**MEMBERS**

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

**SUPPORTING MEMBERS**

Carlton County
Clearwater County
Hedstrom Lumber Company
Hubbard County
Minnesota Nursery & Landscape Association
Pine County

# ANNUAL REPORT
# Minnesota Tree Improvement Cooperative
## January 1-December 31
# 2008

C. Pike, J. Warren, A. David

Department of Forest Resources

College of Food, Agricultural and Natural Resource Sciences

University of Minnesota

## EXECUTIVE SUMMARY

The Minnesota Tree Improvement Cooperative (MTIC) completed its twenty-seventh year in 2008 with fourteen full members and six supporting members. Dues payments in the amount of $62,816 were collected, which included the contract with the MN DNR. Two business meetings were held, one on January 12, 2008 at the North Central Research & Outreach Center (NCROC) in Grand Rapids and another on March 19th at the Cloquet Forestry Center. The MTIC fall workshop was held at Cass County Land Department's facility in Backus on December 11. During 2008, Carrie Pike served as Coordinator, Dr. Andrew David was Director and Jim Warren provided field and technological assistance. Kathy Haiby and Egon Humenburger (both based in Grand Rapids) also provided field assistance.

In 2008, priorities included planting a black spruce seed source trial, planting a tamarack seedling-seed orchard, and collecting ten-year measurements on second-generation jack pine. Five-year measurements were completed on a white spruce comparison trial. Cones were collected from 10 different seed orchards. Cones from 40 full-sib families were collected from crosses made in 2007 at the white pine breeding arboretum in Cloquet and the St Louis County Ellsburg Rd Orchard.

Meetings attended: Pike attended the Society of American Foresters winter meeting in Grand Rapids, Annual meeting of the Superior Woods Tree Improvement Association in Thunder Bay, and Climate change workshop in St Paul. Pike presented to the University of Minnesota Forest Ecology lab in St Paul, the Bemidji State University Center for Research and Innovation, the Minnesota Forest Resource Partnership, and published articles in Urban Habitats and Better Forests.

Grafting of white spruce and white pine will take place in 2009. White pine breeding will be continued. Ten-year measurements of the Zambino open-pollinated white pine progeny test will be completed at three sites. Breeding of red and white pine are planned.

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## A Letter from the Director

Dear Cooperative Members,

As you read through this year's annual report you might notice that there has been a slight change in format. We have intentionally updated the look and feel of the report to make it more readable by including color and placing the technical reports in the Appendix. The sections on Finances, Seed Orchards and Species Reports will retain their familiar style so you can find pertinent information quickly.

Another change instituted for this year will be the invoicing and processing of dues notices. This change has been mandated by the University's switch to a new accounting system. In short, we no longer have the ability to invoice annual dues through the Cooperative. Instead, we will be relying on the University's departmental accountants to invoice, receive and process dues payments. Because we will be working with accountants at the departmental level rather than system wide accountants we expect this transition to be relatively transparent on your side. These changes will be instituted in the upcoming dues cycle so if you have any questions about invoicing and processing of your organization's dues contact Carrie Pike.

What has not changed is the MTIC's commitment to increasing forest productivity through the use of conventional tree improvement practices. While our traditional breeding activities improve the survival and growth rate of each species, previous activities, archived materials and our research ability allow us to address cooperator needs quickly and efficiently. For example, with the increased need for jack pine seed we are able to reclaim first generation seed orchards and put them back into production. Our response to cooperator questions about the value of using improved black spruce seed for aerial seeding resulted in the installation of a new black spruce seed source/stock type trial to compare growth of improved versus unimproved materials on lowland sites. This commitment to address cooperator needs in real time, and under an existing dues structure, marks the MTIC as one of the most responsive forest cooperatives in the region, if not the nation.

As you read through the report I would like to draw your attention to two studies in particular. First, data from the second generation jack pine materials is starting to roll in and be analyzed. The first portion of the analysis is in this report and future analysis and updates will indicate which individuals will be most productive in member seed orchards. With the need for jack pine seed increasing this information is timely indeed! Watch how this analysis unfolds as we will be using a similar method for the second generation white spruce materials that are just a few years behind these jack pine trials. Finally, as part of our commitment to foster research in forest genetics and tree improvement, there is an update from Carrie Pike on her dissertation research related to growth strategies of improved white spruce and their implications for climate change. Enjoy this year's report and know that individually and collectively our dollars are being well spent.

Sincerely,

Andrew David
Director, MTIC
Associate Professor of Forest Genetics

## INTRODUCTION

In 2008, the Minnesota Tree Improvement Cooperative (MTIC) entered its 27th year with 14 full members and six supporting members. Seed orchards for five conifer species are in place: black spruce, white spruce, jack pine, red pine, white pine and now tamarack.

Accomplishments during the 2008 field season included planting a black spruce combination seed source and stock type trial at one location in Koochiching County. In the fall, ten-year tree heights and diameters were measured on second-generation jack pine, and at the MN DNR Ross Lake white spruce progeny test planted in 1986. One white pine trial, "Isabella," established by Cliff and Isabel Ahlgren in the 1980s, was measured and assessed for blister rust as per contractual agreement with support from the Wilderness Research Foundation. Grafting in March, 2008 resulted in the following: 39 jack pine (survival not known) at General Andrews Nursery; 393 white pine (299 remaining, 76% survival) at Itasca Greenhouse; and 46 white pine (40 remaining, 83% survival) at Iron Range Resources' Mineland Reclamation facility in Chisholm. Cones were collected by cooperative members from 10 different seed orchards.

Starting July 1, 2008, the University of Minnesota began using a new enterprise accounting system that, at this writing, was still experiencing major glitches. Accounting procedures have changed dramatically as well, but the Department of Forest Resources maintains an Accounts Specialist who will assist the Cooperative with invoicing and other financial matters. The MTIC staff can no longer handle dues checks or create invoices for dues or workshop registrations. By centralizing these procedures staff is relieved of basic accounting work but may decrease our ability to track down errors.

This report summarizes activities and accomplishments from January 1 to December 31, 2008. It is organized into five major sections: Administration, Finances, Seed Orchards, Species Reports, and Outlook. An Appendix, containing progress reports from current and future projects that involved MTIC staff or resources, follows the Outlook section. The summaries provided have not been peer-reviewed or published, and thus the results may be subject to change upon final analysis.

## ADMINISTRATION

Carrie Pike remains Coordinator of the MTIC, based at the CFANS Cloquet Forestry Center. Jim Warren continues a full-time appointment providing technological and field assistance on projects for the MTIC, the white pine blister rust program, and the Cloquet Forestry Center. Pike coordinates day-to-day operations of the Co-op's finances, communications, reports, data collection and analysis. Warren maintains the Co-op's tree databases, software, and other technical and field assistance.

Dr. Andy David, Director, continues to assist with long-term directives and consultation. His time is divided between research interests in Grand Rapids, the MTIC in Cloquet, and

teaching duties in St Paul. Egon Humenburger, also based in Grand Rapids, is partially funded by the state-legislated funding for white pine blister rust research, and assists on work pertaining to the genetic improvement of white pine. In August 2008, Kathy Haiby accepted a Nursery Manager's position with Greenwood Resources in Oregon. Kathy's field skills and energy will be sorely missed.

The Advisory Committee consists of representatives from each member of the MTIC. It met twice during 2008: January 12 at the North Central Research & Outreach Center (NCROC) in Grand Rapids and again on March 19th at the Cloquet Forestry Center. In September, Gerry Engle (advisory committee from Red Lake) accepted a position managing timber assets on Afognak and Kodiak Islands in Alaska with the Afognak Native Corporation. His energy and attention to detail with be missed. His replacement, Tony Arola – Red Lake's new forest development forester - will be in charge of orchard management. The MTIC fall workshop entitled "A primer on managing cone and seed collections from seed orchards" was held at Cass County Land Department's facility in Backus on December 11. A field tour of the MN-DNR's seed cleaning and storage facilities at Badoura nursery was led by Craig Vansickle. Registration was $20; the meeting was attended by 16 people.

In November 2007, Pike was formally accepted to graduate school at the University of Minnesota in pursuit of her Doctorate degree in Natural Resources Science & Management, under the advisory of Dr. Rebecca Montgomery. Pike enrolled in one class at University of Minnesota-Duluth in spring 2008 and another class at St Paul in fall 2008. A summary of her research progress in 2008 is provided in the Appendix.

On-site visits were made to over 40 different MTIC plantings in 2008 by Pike, Warren & David. Pike attended the winter meeting of the Minnesota SAF in February in Grand Rapids, MN. On February 25 Pike presented "How Will Climate Change Impact the Seed Sources Used to Artificially Regenerate Forests in Minnesota?" in Bemidji hosted by the Center for Research Innovation (CRI), at Bemidji State University. On April 9, Pike presented "How Will Climate Change Impact the Seed Sources Used for Tree Planting in Minnesota - and what can we do about it?" to the Minnesota Forest Resource Partnership in Grand Rapids. With funds graciously provided in part by the Department of Forest Resources, Pike attended a 2-week course "Conservation Genetics" at the Palo Verde Biological Station in Costa Rica from May 15-31. Pike gave a presentation on tree improvement to Vermilion College students at Cloquet on September 25 and attended the annual workshop of the Superior-Woods Tree Improvement Association in Thunder Bay on October 7-8. Pike presented her research plans to the University of Minnesota Forest Ecology laboratory in St Paul on November 1. Pike attended the meeting entitled "Northern Forests in a Changing Climate" on December 2 in St Paul.

## SEED ORCHARDS

Seed orchards are the means by which the MTIC produces genetically improved seed for use in commercial-scale planting programs. Orchards are in place for six species. All first-generation jack pine orchards have been rogued. Five of seven red pine orchards have been rogued and a sixth (Cass-Beltrami-Hubbard County's Blind Lake orchard) was marked in 2008 and is in the process of being rogued. Four improved first-generation white spruce orchards have been established in recent years. A summary of the types and sizes of orchards is shown in Table 4. Tables 5 & 6 list all orchards by species and owner for *Picea*, *Pinus*, and *Larix* orchards. All "research" trials are listed in Table 7. Second-generation trials are included in this list until they are rogued and no longer measured periodically. Cone collections made in 2008 are shown in Table 8.

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

| ***Orchard Type*** | ***Black spruce*** | ***White spruce*** | ***Jack pine*** | ***Red pine*** | ***White pine*** | ***Tamarack*** | ***Total acreage*** |
|---|---|---|---|---|---|---|---|
| First Generation Clonal | 8 | 20 | --- | --- | 14 | --- | 42 |
| First Generation Seedling Seed | 8 | 4 | 27 | 37 | --- | 4 | 80 |
| Improved First Generation Clonal | --- | 10 | --- | --- | --- | --- | 10 |
| Second Generation Full Sib | 4 | 11 | 6 | --- | --- | --- | 21 |
| ***Total acreage by species*** | ***19*** | ***45*** | ***33*** | ***37*** | ***14*** | ***4*** | ***152*** |

**Table 2. *Picea* seed orchards actively managed by the MTIC.**

| *Species* | *Orchard Type* | *Organization* | *Planting* | *Date Planted* | *Size (ac)* | *Live Trees* |
|---|---|---|---|---|---|---|
| Black spruce | 1st Generation Clonal | Koochiching County | Big Falls | 19-May-89 | 2.3 | 61 |
| | | Koochiching County | Larsaybow | 27-May-98 | 4.0 | 59 |
| | | Minnesota DNR | Sturgeon Lake | 01-May-79 | 1.3 | 812 |
| | 1st Generation Seedling | Minnesota DNR | Eaglehead | 17-May-78 | 2.7 | 582 |
| | | Potlatch Forest Holdings, Inc. | Cloquet | 01-May-78 | 3.0 | 580 |
| | | Blandin Paper Company | Blackberry | 22-May-78 | 2.5 | 596 |
| | 2nd Generation | Minnesota DNR | Split Rock | 27-May-92 | 2.4 | 262 |
| | | U of M CFC | Airport 40 | 01-May-95 | 1.1 | 238 |
| | | | ***Totals:*** | ***8 Orchards*** | ***19.3*** | ***3,190*** |
| White spruce | 1st Generation Clonal | Itasca County | Fig. Eight Lake | 02-Sep-87 | 1.1 | 176 |
| | | Lake County | Two Harbors | 02-Sep-87 | 1.0 | 198 |
| | | Minnesota DNR | Cotton | 01-May-77 | 12.0 | 206 |
| | | Potlatch Forest Holdings, Inc. | Cloquet | 01-May-77 | 3.3 | 140 |
| | | St. Louis County | Ellsburg Rd. | 11-May-88 | 1.5 | 189 |
| | | Blandin Paper Company | Arbo | 01-May-76 | 1.5 | 121 |
| | 1st Generation Seedling | Blandin Paper Company | Latimer | 15-May-67 | 4.1 | 224 |
| | 1-1/2 Generation Clonal | Minnesota DNR | Split Rock | 02-Sep-01 | 3.7 | 255 |
| | | Potlatch Forest Holdings, Inc. | Gillogly Road | 01-Apr-03 | 2.1 | 187 |
| | | Red Lake | Redby | 01-Apr-04 | 0.9 | 157 |
| | | Blandin Paper Company | College | 05-Sep-00 | 2.9 | 780 |
| | 2nd Generation Seedling | Lake County | Ostman Pit Road | 06-Jun-05 | 1.3 | 818 |
| | | Itasca County | Wabana Lake | 20-May-03 | 1.8 | 693 |
| | | Minnesota DNR | Eaglehead | 03-Jun-03 | 1.8 | 401 |
| | | Minnesota DNR | Eaglehead | 01-May-05 | 1.3 | 764 |
| | | St. Louis County | Ellsburg Rd. East | 06-Jun-03 | 2.1 | 393 |
| | | Blandin Paper Company | Feeley | 01-May-05 | 2.4 | 900 |
| | | | ***Totals:*** | ***17 Orchards*** | ***44.8*** | ***6,602*** |

**Table 3. *Pinus sp.* and *Larix laricina* orchards actively managed by the MTIC.**

| *Species* | *Orchard Type* | *Organization* | *Planting* | *Date Planted* | *Size (ac)* | *Live Trees* |
|---|---|---|---|---|---|---|
| Jack pine | 1st Generation Seedling | Cass/Beltrami/Hubbard Counties | Deep Portage | 30232 | 3.4 | 492 |
| | | Crow Wing County | Crow Wing | 31202 | 2.1 | 247 |
| | | Iron Range Resources | Calumet | 30210 | 1.7 | 220 |
| | | Minnesota DNR | Longprairie | 30820 | 4 | 465 |
| | | Minnesota DNR | Nickerson | 30817 | 2.4 | 387 |
| | | Potlatch Forest Holdings, Inc. | Gillogly Rd. | 30495 | 5.5 | 183 |
| | | Red Lake Nation | Redby | 31896 | 1.8 | 516 |
| | | St. Louis County | Ellsburg Rd. | 32273 | 1.6 | 279 |
| | | Wausau-Mosinee Paper Corp. | Barnes | 32290 | 4.1 | 549 |
| | 2nd Generation Seedling | Crow Wing Co./MN DNR | County Line | 36281 | 2.6 | 1264 |
| | | St. Louis / Iron Range Resources | Ellsburg Rd. East | 36292 | 3.78 | 2064 |
| | | | ***Totals:*** | ***11 Orchards*** | ***33.0*** | ***6,666*** |
| White pine | 1st Generation Clonal | Itasca County | Bass Lake | 19-May-98 | 5.7 | 498 |
| | | Itasca Greenhouse | Sayward | 16-Jun-05 | 0.8 | 425 |
| | | Minnesota DNR | Split Rock | 25-May-93 | 1.0 | 88 |
| | | Minnesota DNR | St. Francis | 15-May-85 | 3.0 | 319 |
| | | St. Louis County | Ellsburg Rd. | 02-May-90 | 1.1 | 233 |
| | | St. Louis County | Ellsburg Rd. East | 21-Jun-99 | 2.5 | 237 |
| | | | ***Totals:*** | ***6 Orchards*** | ***14.1*** | ***1,800*** |
| Red pine | 1st Generation Seedling | Cass/Beltrami/Hubbard Counties | Blind Lake | 10-Sep-91 | 5.3 | 1,682 |
| | | Minnesota DNR | Cotton | 29-Jul-81 | 4.5 | 462 |
| | | Minnesota DNR | Eaglehead | 25-Jun-81 | 3.6 | 289 |
| | | Plum Creek Timber Company | Petenwell | 24-Apr-90 | 5.5 | 464 |
| | | Potlatch Forest Holdings, Inc. | Gillogly Rd. | 10-Jul-81 | 6.6 | 461 |
| | | St. Louis County | Ellsburg Rd. | 09-May-88 | 5.5 | 531 |
| | | Wausau-Mosinee Paper Corp. | Mosinee | 23-May-90 | 5.7 | 1,174 |
| | | | ***Totals:*** | ***7 Orchards*** | ***36.7*** | ***5,063*** |
| Tamarack | 1st Generation Seedling | Minnesota DNR | Split Rock | 12-May-08 | 4.3 | 2,010 |
| | | | ***Totals:*** | ***1 Orchard*** | ***4.3*** | ***2,010*** |

**Table 4. Research trials planted by the MTIC.**

| *Species* | *Planting Type* | *Year planted* | *Organization* | *Planting Name* | *Last measured* | *Next Scheduled* |
|---|---|---|---|---|---|---|
| White spruce | Comparison trial | 1993 | Minnesota DNR | Dago Lake Rd | 2002 | 2012 |
| | | 1993 | Plum Creek Timber Company | Gordon | 2002 | 2012 |
| | | 1993 | Potlatch Forest Holdings, Inc. | Orr | 2002 | 2012 |
| | | 1993 | Blandin Paper Company | Hwy 61 | 2002 | 2012 |
| | | 1995 | Potlatch Forest Holdings, Inc. | Hill City | 2000 | n/a |
| | | 1995 | U of M | CFC-Airport 40 | 2005 | 2010 |
| | | 2003 | Koochiching County | Little Fork | 2007 | 2012 |
| | | 2003 | Minnesota DNR | Side Lake | 2007 | 2012 |
| | | 2003 | Potlatch Forest Holdings, Inc. | Brookston | 2007 | 2012 |
| | | 2003 | St Louis County | Jean Duluth Rd | 2007 | 2012 |
| | | 2003 | Blandin Paper Company | Wilson Lake | 2007 | 2012 |
| | Progeny test | 1986 | Lake County | Finland | 2005 | 2015 |
| | | 1986 | Minnesota DNR | Nickerson | 2005 | 2015 |
| | | 1986 | Minnesota DNR | Ross Lake | 2008 | 2015 |
| | | 1986 | St louis County | Rabbit Lake | 2005 | 2015 |
| | | 1986 | Blandin Paper Company | Nine-mile | 2005 | 2015 |
| | 2nd generation population | 2003 | Itasca County | Wabana Lake | 2007 | 2012 |
| | | 2003 | St. Louis County | Ellsburg East | 2007 | 2012 |
| | | 2003 | Minnesota DNR | Eaglehead | 2007 | 2012 |
| | | 2005 | Lake County | Ostman Pit | --- | 2009 |
| | | 2005 | Minnesota DNR | Eaglehead | --- | 2009 |
| | | 2005 | Blandin Paper Company | Feeley | --- | 2009 |
| White pine | Progeny test | 1999 | St Louis County | Ellsburg Rd | 2003 | 2008 |
| | | 1999 | USFS | Grand Marais | 2003 | 2008 |
| | | 1999 | ORSO | ORSO | 2003 | 2008 |
| Black spruce | Full-sib progeny test | 1995 | U of M | CFC-Airport 40 | 1995 | n/a |
| Red pine | Comparison trial | 2007 | Beltrami County | Lake Bemidji | --- | 2011 |
| | | 2007 | Plum Creek Timber Company | Manistique | --- | --- |
| | | 2007 | Potlatch Forest Holdings, Inc. | Lake George | --- | 2011 |
| | | 2007 | U of M | CFC | --- | 2011 |
| | | 2007 | St louis County | NE Grade | --- | 2011 |
| Jack pine | 2nd generation population | 1999 | St Louis / Iron Range Resources | Ellsburg E. | 2003 | 2008 |
| | | 1999 | Crow Wing / Minnesota DNR | County Line Rd | 2003 | 2008 |

**Table 5. Cones collected by MTIC Cooperators in 2008.**

| *Species* | *Agency* | *Orchard* | *# bushels* |
|---|---|---|---|
| White spruce | Blandin Paper Company | Latimer | 2.5 |
| | | Arbo | 21.0 |
| | | College | 5.3 |
| | Itasca County | Figure Eight Lake | 3.0 |
| Jack pine | Crow Wing County | Crow Wing | 5.0 |
| | Red Lake Nation | Redby | 8.0 |
| | Minnesota DNR | Nickerson | 5.0 |
| | | Long Prairie | 5.0 |
| White pine | St. Louis County | Ellsburg Rd | 30.0 |
| | Minnesota DNR | St. Francis | 66.0 |
| | | ***Total:*** | 150.8 |

## SPECIES REPORTS

### Black spruce

*Status*

In 2008, black spruce crops were moderate to excellent. The **Koochiching County Big Falls** orchard had a moderate crop. Many trees in this orchard are suffering from a lowered water table, and are not producing at an optimum. The **Larsaybow** orchard was not visited this year but surviving grafts are growing well. The **MN DNR's Sturgeon Lake**, **Eaglehead**, and **Split Rock** orchards had excellent crops that will be captured in winter 2009. **Sturgeon Lake** orchard was thinned last year and should be used for seed collection in the future. **Blandin's Blackberry** orchard remains in excellent condition, and had a sizeable crop in 2008.

*Short and long-term planning*

Potlatch's Cloquet orchard remains in good condition. While considered abandoned due to change of ownership, cones could potentially be collected with permission from SAPPI. Blandin's Blackberry orchard may require additional thinning in the future to ease spacing constraints. The sister trial to the Blandin and Potlatch black spruce orchards is located at the Cloquet Forestry Center and has not been thinned.

The black spruce comparison trial was planted on one site in the spring of 2008. A freak snowfall in mid-April damaged many of the seedlings ear-marked for this trial subsequently seedlings were available for planting at one site only. The site is located west of International Falls on land managed by Koochiching County. Kudos to the Koochiching County crew for assisting in flagging and planting this trial.

## White spruce

*Status*

White spruce cones were relatively scarce across the state for the second year in a row in 2008. After the bumper crop of 2006, this is not surprising. The **St Louis County Ellsburg Rd** orchard is recovering nicely from the topping it received in fall of 2007. The majority of trees in the **MN DNR Cotton** orchard, which was topped in 2006, were devoid of cones, though individual trees were producing moderate crops, supporting the resident insect populations. Several trees had moderate cone crops at **Lake County's Two Harbors'** orchard. **UPM-Blandin** harvested cones at all three of their orchards (**Latimer, Arbo and College**) by targeting top-ranked clones for collection. **Red Lake's Redby** orchard, established in 2004, has received intensive management. Survival of out-planted grafts is high - only one graft was noted as dead in 2008. Early survival at the **MN DNR's** improved-first generation orchard (abbreviated 1-1/2 generation clonal in Table 5) at **Split Rock** was mediocre. Many of the grafts were replaced in 2007 but mortality needs to be re-assessed in 2009. Survival at **Potlatch's** new improved-first generation orchard at **Gillogly Rd** orchard complex was fair.

Measurements of five-year height growth and survival were completed for the 2003 white spruce comparison trials. These included **Potlatch's Brookston, Koochiching County's Little Fork, St Louis County's Jean Duluth Rd and Blandin's Wilson Lake**. One site, **MN DNR Side Lake,** was not measured due to low survival and may be abandoned. In addition, 23-year tree heights and diameters were measured at MN DNR's Ross Lake progeny test in summer 2008 as part of Pike's graduate field work.

*Short and long-term planning*

White spruce orchards have produced abundant crops over the years, but seed yields have been increasingly compromised by cone and seed insects. Infected cones should be removed from orchards while insects are still residing in the cones. This subject was covered by Steve Katovich, Mike and Jana Albers at the MTIC fall workshop on October 11, 2007. The development of improved first-generation orchards should continue to provide a reliable seed-source until the second-generation populations are mature. Second-generation populations will receive minor thinning to alleviate spacing constraints, but will not be rogued to any large extent due to the need to preserve genotypes for the program.

Latimer orchard is still slated for retirement in the near future, having served Blandin's tree improvement program well since its establishment in 1967.

Most living grafts in new improved first-generation orchards are well-established but will require pruning of rootstock and regular mowing between rows to reduce grass competition.

In 2009, three second-generation plantings (planted in 2005 at MN DNR's Eaglehead, Lake County's Ostman Pit Rd, and Blandin's Feeley site) will be measured for five-year survival and height growth.

Ross Lake progeny test was thinned only recently and was not measured following 15- and 20-years of growth. It will be re-measured again along with Lake County Finland, MN-DNR Nickerson, and Blandin's Nine-Mile in 2015 for 30-year measurements.

## Jack pine

*Status*

Cone crops in jack pine orchards were generally low in 2008. Cones were collected at **Red Lake's Redby** orchard and **Crow Wing County's** first-generation orchard. As in 2007, cones at **Iron Range Resources Calumet** were moderate and not collected as of this writing. At **Cass, Beltrami and Hubbard County's** joint **Deep Portage** orchard efforts to remove competing vegetation and release orchard trees were begun in 2007, and are ongoing. At **DNR Longprairie** management will be limited to cone collections and thinning, due to its remote location. Trees that succumb to root collar weevil will be removed, but chemical treatment for living, infested trees will not be attempted.

The two second-generation jack pine plantings, **Crow Wing Co/MN DNR County Line Rd**, and **St Louis Co/Iron Range Resources Ellsburg Rd East**, remain in excellent condition. Ten-year measurements were completed in fall 2008 and will be used to make selections for future breeding and grafting from these sites. A summary of this dataset is included in the Appendix. Cones have been abundant for several years but picking has been reserved until selections are completed.

*Short and long term planning*

The completion of measurements on the second-generation population is a notable achievement for the Cooperative's jack pine program. New seedling-seed orchards or grafted orchards will be established using seed or scion from these sites to replace aging first-generation orchards. These new orchards will provide seed for the burgeoning demand for jack pine into the future. Deer browse of jack pine plantations remains a severely limiting factor to successful regeneration. Jack pine grafting success has been low in past years due to difficulties in matching rootstock to scion material however a total of 207 live grafts at General Andrews Nursery in Willow River should be out-planted to a new site as early as 2009. Future orchards are likely to consist largely of seedling-seed orchards, complemented by one or two grafted orchards.

## Red pine

*Status*

Following a bumper crop in 2007, red pine cones were generally scarce in 2008. No cones were collected at any MTIC orchard. Orchards that remain in good standing include **MN DNR – Cotton orchard**, **St Louis – Ellsburg Rd**, and **Potlatch – Gillogly Rd**. **Plum Creek Timber Company's Petenwell** orchard, located in south-central Wisconsin, was visited this fall. Cones were scarce and an application of a balanced fertilizer was recommended to bolster tree health. Measurements at the **Cass-Beltrami-Hubbard County's Blind Lake** orchard were completed in 2008 and the orchard is currently being rogued. Approximately 100 trees were removed from **MN DNR's Eaglehead** last winter to increase spacing in the orchard. In addition, fifty trees were fertilized in spring 2008 to bolster cone production.

A mortality survey was performed on sites where red pine seed source trials were planted in 2007. Survival was low to moderate across sites. The trial on **Plum Creek** land in

**Manistique**, Michigan was abandoned due to exceptionally low survival. Survival was not assessed at **St Louis County – NE Grade**, but all seedlings were protected with Vexar® tubes upon planting. Survival will be assessed at a later date.

**Table 6. Percent survival by seed source at red pine comparison trials planted in 2007.**

| Seed Source | Cloquet Forestry Center | Beltrami Co. (Lake Bemidji) | Potlatch (Lake George) |
|---|---|---|---|
| MN DNR Eaglehead orchard | N/A | N/A | 54 |
| Potlatch Gillogly Rd orchard | 53 | 69 | 59 |
| St Louis Ellsburg Rd orchard | 52 | 73 | 63 |
| Woods Run | 49 | 49 | 47 |
| Overall survival by site | 51 | 63 | 56 |

*Short and long-term planning*

The red pine cone crop in 2008 was extremely low. This is not surprising after the abundant crop from 2007. Most orchards would still benefit from future thinning, which should be timed to coincide with cone collection. This includes MN DNR's Eaglehead where cone production will likely increase after overcrowding is eased.

Grafted orchards will enhance seed production from first-generation orchards by shortening the time to cone production, increasing crown management options, and allowing for a fully-stocked, evenly-spaced orchard. As soon as grafting methodology is perfected, a new series of grafted orchards will be planted to supplement current orchard production. Pollen was collected in spring 2008 for making controlled crosses as early as spring 2009.

## White pine

*Status*

The white pine cone crop was generally abundant in 2008. A large crop was harvested at **St Louis County's Ellsburg Rd** orchard and at **MN DNR's St Francis orchard**. Several grafts at **Sayward's white pine** orchard died this summer, but they were still able to pick some cones from surviving small grafts. At Tofte, open-pollinated cones were collected from 100 new genotypes for future progeny testing. The seeds were extracted by Carrie Sweeney at Oconto River Seed Orchard where they will be screened in the future.

Five selections from Tofte were grafted at Iron Range Resources in Chisholm for a total of 46 grafts. These grafts are slated for the Cloquet breeding arboretum, with extras distributed to MTIC cooperators. At Itasca Greenhouse, a total of 393 white pine grafts were produced from nine plus-tree selections from **Red Lake** and a variety of genotypes from the MTIC blister rust program. **Red Lake** located a site that will be home to a future white pine orchard just south of the reservation.

Full-sib seeds were collected from 40 crosses bred at the CFC arboretum and St Louis County Ellsburg Rd in 2007. Currently the seed is being extracted and will reside in storage at the Forest Biology facility in Grand Rapids.

*Short and long-term planning*

The white pine blister rust trials planted in conjunction with Paul Zambino (USDA Forest Service) will be measured in spring 2009 following their tenth growing season. Three of the original five sites remain: 1) St. Louis County's Ellsburg Rd, 2) Forest Service property near Grand Marais, MN and 3) Forest Service's Oconto River Seed orchard near Langlade, WI. Data on survival, tree height, and presence/absence of rust will be collected. Grafting for a future white pine orchard at Red Lake began in 2008, hosted by Itasca Greenhouse. Nine plus trees located on the reservation were grafted, along with selections from the MTIC blister rust program.

Plans for the upcoming year include scion collection and grafting from select trees at the U.S. Forest Service "Moose Fence" planting in Tofte, MN. Trees targeted for grafting consist primarily of those from which open-pollinated cones were collected in fall 2008. This work will be supported in part by monies provided by the Forest Service to conserve genetic diversity in species threatened by exotic insects or diseases. Grafts will be established at the white pine breeding arboretum at CFC and the USDA Forest Service Oconto River Seed Orchard in Langlade, Wisconsin.

In conjunction with the Blanchette laboratory and with financial assistance from the WRF grant we will be investigating the inheritance of the occluded stomate trait in families with P327 used as a male or female parent as well as families without P327 used as a parent. P327 has stomates that are occluded by needle wax and it consistently produces seedlings with significantly higher survival rates than other parents when these seedlings are challenged with blister rust in a greenhouse setting. If this trait is heritable and it serves as a mechanism to physically exclude the hyphae of the blister rust then it may be advantageous to screen other trees for the occluded stomate trait before breeding them with P327.

Long-term plans in white pine include establishment of a multi-site progeny trial to test survival and growth traits of individuals currently in our seed orchards as well as selected individuals from the US Forest Service's Tofte, Minnesota trial.

## OUTLOOK

The MTIC secured its 27th year in good financial standing. Itasca County did not renew membership in 2008. The contract with the MN DNR, renewed in 2007, will be revisited again at the end of FY09 for another biennium. Warren's appointment with the Cloquet Forestry Center is expected to continue. A three-year grant with the Wilderness Research Foundation will end at the end of FY09. State-appropriated money for genetics research related to improving resistance to blister rust is expected to continue in the next year but the short and long-term status of this funding is not known. Continued collaboration with USDA Forest Service's established white pine blister rust screening program is expected to aid in selecting genotypes for planting into MTIC orchards.

Tree breeding is anticipated to begin for red pine and white pine in 2009. Data collection from the 2nd generation jack pine populations should be completed so that roguing can begin in the next year. Grafting from these trials will begin to create improved first-generation orchards. In the future, crosses will be made to create new advanced-generation orchards.

Grafting in winter 2009 will take place at MN DNR General Andrews Nursery to graft all clones from the white spruce breeding arboretum. The arboretum serves as a clone bank for first-generation material and needs to be moved due to increased measures to eliminate pathological innoculum from surrounding nursery beds. New grafts will be planted to a different location to be determined. Additional white pine will be grafted from the Tofte, Minnesota site in collaboration with the USDA Forest Service. In addition, rootstock was potted at Red Lake for producing additional grafts for a future white pine orchard. Fifth year measurements will be taken from second-generation white spruce in fall 2009.

## 2009 Cooperative Work Plan

**Black spruce**

- Mortality survey of planted seedlings at black spruce trial
- Visit all orchards, assess management needs.

**White spruce**

- Graft all clones from spruce breeding arboretum at General Andrews Nursery. Find location of new clone bank for out-planting these grafts.
- Reassess survival at all improved first-generation orchards. Prune rootstock, re-tag, and update survival.
- Measure five year heights at second-generation white spruce populations at MN DNR Eaglehead, Lake County – Ostman Pit Rd, Blandin Paper Company – Feeley Unit. (fall 2009)
- Pike's graduate research

**Jack pine**

- Out-plant potted grafts at General Andrews Nursery to new orchard (MN DNR).
- Continue thinning first-generation orchards.
- Continue reclamation of Cass-Beltrami-Hubbard Deep Portage orchard.
- Make plans for roguing 2$^{nd}$-generation populations for production of improved 2$^{nd}$ generation seedling-seed orchards.

**Red pine**

- Tree breeding spring 2009
- Finish roguing Cass-Beltrami-Hubbard County red pine orchard.
- Thin orchards and harvest cones.

**White pine**

- Grafting winter 2009 from ortets at Tofte.
- Breeding at CFC arboretum and/or St Louis County Ellsburg Rd.
- WRF project- measure Mukluk planting in Ely
- May: obtain ten-year data (survival, tree heights, blister rust incidence) on three open-pollinated trials established by Dr. Paul Zambino (USDA Forest Service) in 1999.
- eSEM analysis of inheritance of occluded stomates

## APPENDIX

### Five year results of a white & black spruce seed-source trial

Introduction

White spruce is an important tree species for reforestation efforts to members of the Minnesota Tree Improvement Cooperative. The Co-op has invested heavily in the program through the establishment of ten grafted and one seedling-seed orchard(s). Five sites containing second-generation material were out-planted in 2003 and 2005. Orchards have produced prolific amounts of seed which are used widely for reforestation programs across the state.

In 2003, the Co-op gathered seed from a variety of improved sources to test actual gains in productivity that are possible through the use of orchard seed over woods run. A black spruce source was also included for comparison. Results from the five-year data collection appear below.

Material

All seed was collected from open-pollinated cones at the following orchards or locations:

1. Black spruce: Blandin's Blackberry black spruce orchard.
2. High-gain: seed collected from two highest ranking trees at Blandin's Latimer white spruce orchard (see Latimer below for orchard description).
3. DNR Cotton: MN DNR's Cotton orchard, post-roguing, consisting of parents with origins in Ottawa Valley region of Ontario.
4. Blandin Latimer: general collection from Blandin's Latimer orchard, post-roguing, consisting of genotypes selected from Minnesota forests.
5. Unrogued orchard: Potlatch's Cloquet orchard, prior to roguing, consisting of parents with origins in Ottawa Valley region of Ontario.
6. Woods Run: general collection from Hill City, MN.

Trial Locations

1. Jean Duluth (north of Duluth), managed by St Louis County Land Department
2. Little Fork, managed by Koochiching County Land Department
3. Brookston (north of Cloquet), managed by Potlatch Corp.
4. Wilson Lake (north of Grand Rapids), managed by Blandin Paper Company

Design

Five replications of 81-tree blocks for each of the six sources. At Little Fork, a portion of the planting was not measured due to high mortality and difficulty in locating surviving trees.

Methods

Tree heights and survival were recorded following the fifth growing season. The site in Little Fork was measured following the sixth growing season. Tree heights were measured with a metric height pole to the nearest millimeter. Analysis of variance and Tukey's HSD method were used to determine significance within a site.

Results

Analysis of variance was significant for all factors at each site and across sites: site, block and seed source. Across sites, average tree heights for black spruce was greater than all others sources (Figure 1). All orchard sources, except for the un-rogued orchard, were taller than woods run.

At each site, some exceptions occurred. At Brookston, high-gain and Cotton were similar to woods run, but all three were greater than the un-rogued orchard, Latimer and black spruce (Figure 2). At Jean Duluth all white spruce sources were statistically similar and smaller than black spruce. At Wilson Lake orchard sources of white spruce were all significantly greater than woods run. At Little Fork, high-gain sources were greater than un-rogued orchard, general collections from Latimer and woods run. Survival varied by site and source (Figure 3). No seed source exhibited high mortality consistently at all sites. Percent differences in tree height of orchard seed relative to woods run source are presented in Table 1. Table 2 shows percent differences in height at each site.

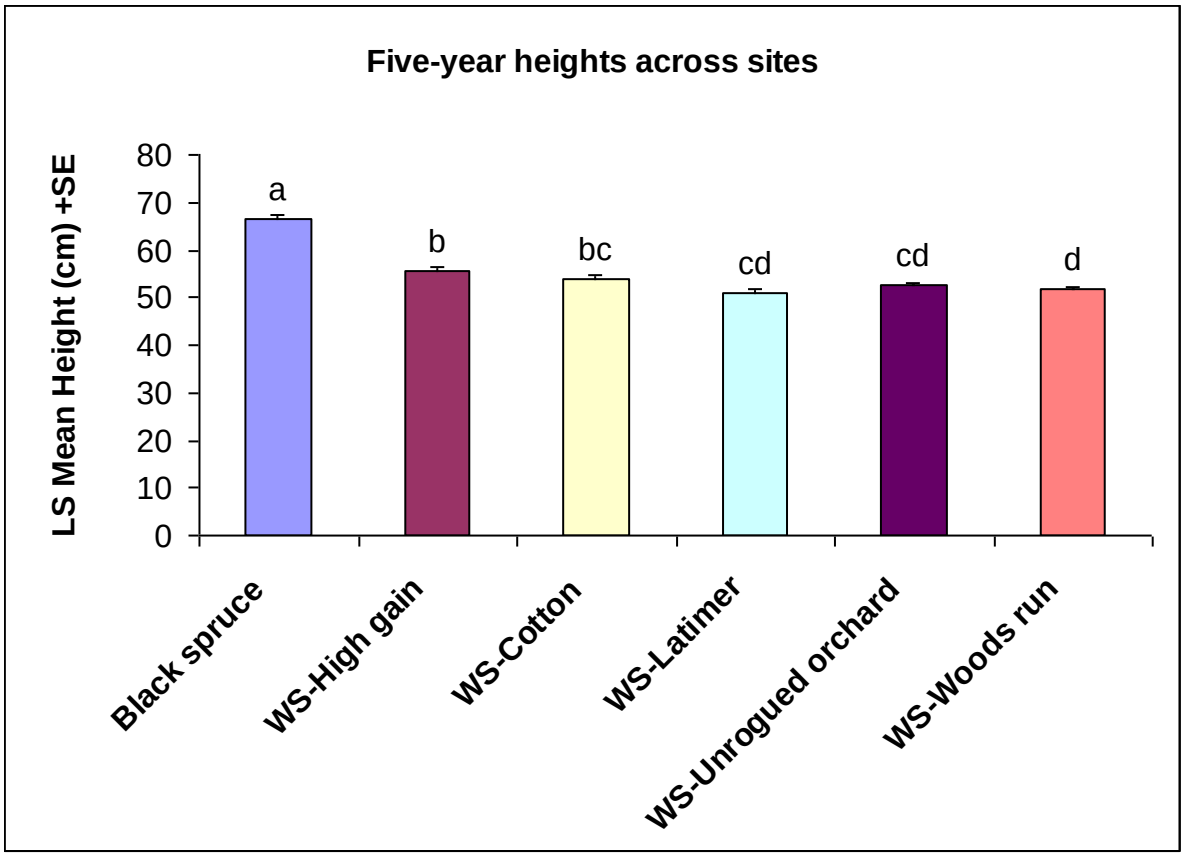


**Figure 1. Averaging across blocks and sites, the least-squared mean tree heights for all six sources. Different letters above the bar indicate significance using Tukey's HSD test at $p < 0.05$.**

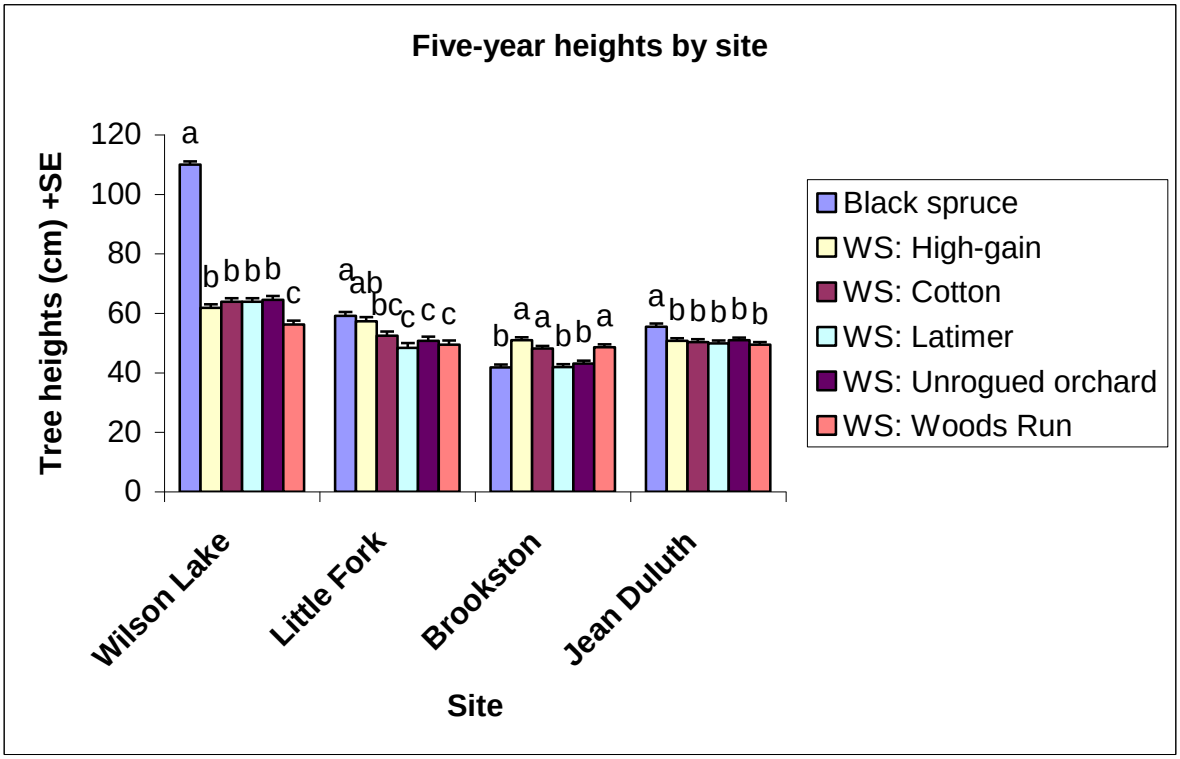


**Figure 2. Least-squared mean tree heights at each site for each source. Letters above the bars indicate significant differences ($p < 0.05$) within that site only.**

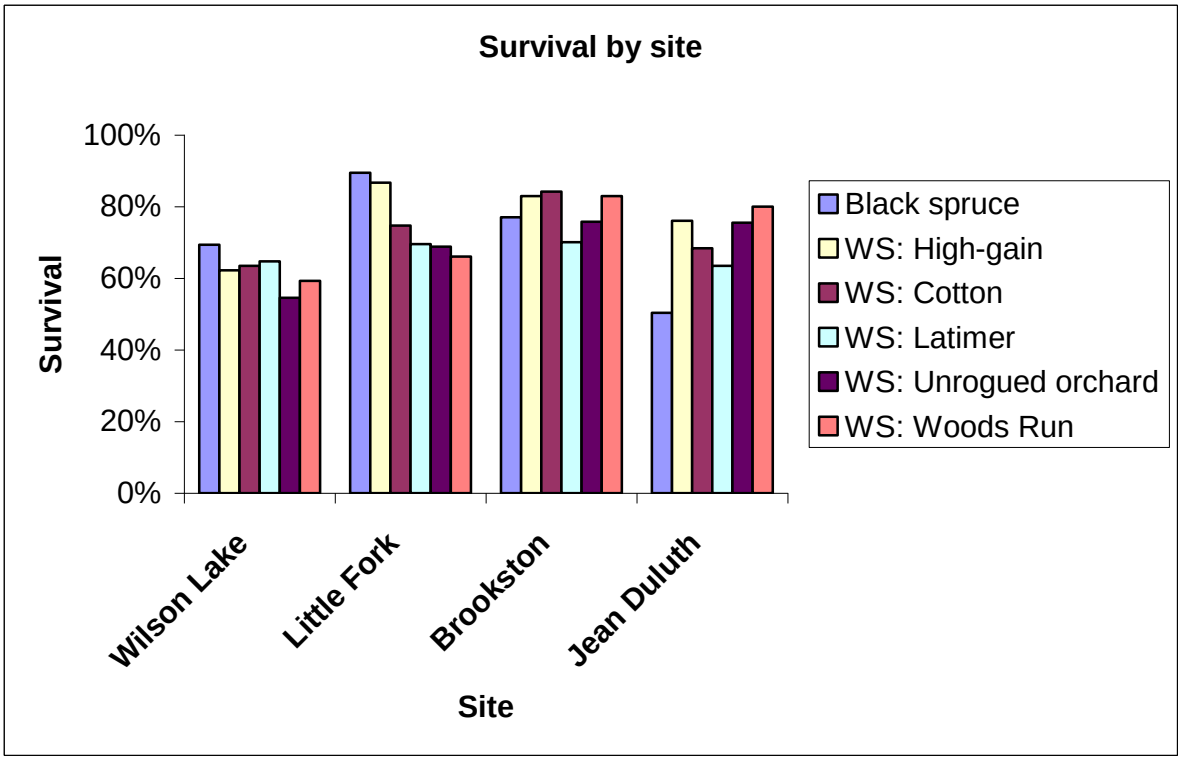


**Figure 3. Percent live trees of each source at each site.**

**Table 1. Percent gain (or loss) in height growth between four improved sources of white spruce and woods run averaged across sites. (For all % gains > 0, tree heights of the orchard source exceeded woods run. Negative percents indicate reduced growth relative to woods run source.)**

| *Across sites* | **Woods Run** |
|---|---|
| **High Gain** | 7.1% |
| **Cotton** | 4.2% |
| **Latimer** | -1.3% |
| **Unrogued** | 1.5% |

**Table 2. Percent gain (or loss) in height growth between four improved sources of white spruce and woods run by site. (When % > 0, tree heights of the orchard source exceeded woods run. Negative percents indicate reduced growth relative to woods run source.)**

| *Wilson Lake* | **Woods Run** |
|---|---|
| **High Gain** | 9.0% |
| **Cotton** | 12.0% |
| **Latimer** | 12.0% |
| **Unrogued** | 12.9% |
| | |
| *Little Fork* | |
| **High Gain** | 13.9% |
| **Cotton** | 5.9% |
| **Latimer** | -2.2% |
| **Unrogued** | 2.6% |
| | |
| *Brookston* | |
| **High Gain** | 4.5% |
| **Cotton** | -1.1% |
| **Latimer** | -16.2% |
| **Unrogued** | -12.9% |
| | |
| *Jean Duluth* | |
| **High Gain** | 2.5% |
| **Cotton** | 1.7% |
| **Latimer** | 0.8% |
| **Unrogued** | 2.8% |

Discussion/Conclusions

Tree heights at these sites reveal large inter-specific differences between black and white spruce at year five, with heights of black spruce generally exceeding white by a large margin. Many seedlings had sustained low-moderate levels of winter-burn at the nursery due to a snowless winter just prior to out-planting. Seedlings with exceptional damage were culled prior to planting resulting in one fewer trial than initially planned. The black spruce was especially burned, and its performance is likely conservative. At Wilson Lake, black spruce trees were

extremely large for reasons that are not yet apparent. The water table at this site is high and may have contributed to its exceptional growth performance. Early height growth of black spruce generally exceeds white spruce (C. Mohn personal communication) but these differences are expected to be less pronounced in the future. Volume of white spruce is expected to exceed black spruce by a large margin in future years when diameter reaches breast height.

Survival hovered between 60-80% at all sites, which is moderate but generally acceptable for spruce plantations where volunteers such as aspen and balsam are associated and tolerated for their wood value. Jean Duluth was treated with herbicide before and after planting to help control persistent aspen regeneration. In Little Fork, vegetation management was performed prior to planting but not since (the site was a former hay field). The eastern side of the planting was fairly wet with high mortality and tall grass and will likely be abandoned. Conditions in the western half were more optimal for white spruce with drier soils and less dense vegetative competition. At the Brookston site, trees were growing well on a gently sloping southern-exposure (which had been trenched prior to planting), but suffered in height growth by moderate amounts of deer-browse. Trees at Jean Duluth also suffered losses in height growth due to herbivory although the cause was likely rabbit instead of deer browse.

Gains in height growth at year five were variable at this early stage of growth. Despite the winter-burn, deer / rabbit browse, and drought in subsequent years since planting the improved sources performed well across sites relative to woods run source at age five. A fifth site, located north of Hibbing on MN DNR land, will be visited and surveyed to determine whether it should be abandoned due to low survival. High-gain material and moderately improved sources (Cotton orchard, unrogued orchard) did not suffer increased mortality in exchange for height growth.

## Update on white pine blister rust research

Submitted by R. Blanchette

White pine blister rust caused by *Cronartium ribicola* is a damaging non-native disease of five-needled pines in North America. Efforts to control the disease and mitigate damage to date have been only somewhat effective. Recent efforts to improve the health of eastern white pine and reestablish the tree as a dominant species in the upper Midwest have focused on identification and propagation of disease-free eastern white pine (*Pinus strobus*) growing in areas with a high incidence of blister rust. Many of these selections have been shown to resist infection following artificial inoculation with *C. ribicola*. In this study, 13 eastern white pine families derived from controlled pollination of selections previously determined to possess putative resistance as well as susceptible selections were inoculated with *C. ribicola*. Mortality data from inoculation studies show superior survivability in three families with over 60% of seedlings able to survive the 52 week post-inoculation monitoring period compared to 0-10% survival of the most susceptible families. Primary needles were collected for histological analysis from all inoculated families 4 weeks after inoculation and from selected families 6.5 weeks and 38 weeks after inoculation. Histological observations of infection sites show distinct resistance reactions in the families more likely to survive infection based on mortality data. Analysis of the reactions in susceptible families revealed extensive hyphal colonization of the vascular bundle and adjacent mesophyll cells that appear uninhibited by tree responses. Collapsed cells adjacent to infection sites, heavy deposition of phenolic compounds and abnormal cell growth were documented more frequently in resistant families and appear to play an integral role in the ability of these eastern white pine families to impede growth of *C. ribicola* in primary needle tissue.

Jacobs, J. J., T. A. Burnes, J. A. Smith, C. Sweeney, A. J. David, and R. A. Blanchette. 2008 Survival and histopathology of eastern white pine seedlings from controlled crosses infected with *Cronartium ribicola.* Phytopathology 98:S73

Jacobs, J.J., T. A. Burnes, A, J. David and R. A. Blanchette. Histopathology of Primary Needles and Mortality Associated with White Pine Blister Rust in Resistant and Susceptible *Pinus strobus*. Forest Pathology In press.

## Family performance of second-generation jack pine in two locations in Minnesota

C. Pike & J. Warren

Abstract

Tree heights and survival at two full-sib progeny tests established in 1999 were measured after 3, 5, 8 and 10 growing seasons. In addition, tree diameters, stem form and cone stature were also assessed in 2008 after ten years of growth. Heritabilities were generally low for growth traits but high for stem form and cone stature. Significant genotype by environmental interactions were found for tree height and diameters. These interactions preclude the development of a single seed-zone of advanced-generation jack pine. Further assessments of gall rust, branch angle, and cone serotiny should be completed prior to roguing.

### Introduction

The Minnesota Tree Improvement Cooperative began a program to genetically improve jack pine in the early 1980s. Ten seedling-seed orchards were established across a large portion of northern Minnesota using seed from plus-trees selected from across the Lake States. Each orchard was planted in a randomized complete block design with single tree plots. Tree heights were measured, and combined index selection was used to rogue out poor performing trees.

The fifty top-ranking trees at each orchard were selected for mating in an aggressive breeding program at nine of these orchards starting in 1993. Trees were ranked sequentially at each site to assign mates using positive assortative breeding with single-pair mating. Each tree selected for mating was designated as either a male or female so that no family was represented more than once in any cross at any orchard or across orchards. As such, each full-sib family represents a unique family and is unrelated to other crosses. Crosses were completed at Potlatch Kallstrom, MN DNR Bemidji, Crow Wing County, MN DNR Longprairie, IRRRB Calumet, MN DNR Nickerson, St Louis County Ellsburg Rd, Potlatch Gillogly Rd. Seed from these crosses was grown together as one second-generation population representing the top genotypes from all orchards.

### Methods

Full-sib seeds were sent to IRRRB in Chisholm, Minnesota for germination in spring 1998 and were grown in 4A-sized styroblocks until planting. In 1999, 143 families were planted at St Louis County orchard complex at Ellsburg Rd (north of Cotton, Minnesota) in collaboration with Iron Range Resources. A subset of 100 families was planted at Crow Wing County (south of Fort Ripley) in collaboration with the MN DNR. Two additional sites planted in 1999 were later abandoned due to plantation failure. Each site was laid out with 18 randomized complete blocks using single-tree plots. Trees were planted at 8 x 8 foot spacing. Tree heights were measured after three (2001), five (2003), eight (2006) and ten (2008) growing seasons. Tree heights in 2001 and 2003 were measured with a metric height pole to the nearest centimeter. Eight and ten-year heights were measured with a Haglof® hypsometer to the nearest decimeter, and calipers were used to measure tree diameter to the nearest millimeter. Stem form was assessed twice, once in 2003 and again in 2008 using a 6 point scale developed for jack pine in New Brunswick (Fullarton, 2001):

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

In 2008, cone stature was also assessed for each tree using a 2-point system. Cones were classified as "upright," if cones were straight, or "curled" if they were bent around the tree branch. This trait may have value for improving seed production since curled cones may produce half as many seeds: scales on the underside of a curled cone generally don't open or contain seed (C. Vansickle, personal communication). Rust was assessed in 2003 at both sites with a 4 point scale:

0=no rust
1=minor branch rust
2=multiple branch rusts
3=stem rust

Analysis of variance was performed using general linear models in SAS (version 9.1.4, 2004) with the model below, where S=Site (i=2 sites), B=Block (j=18 at each site), F=Full sib Family (k=143 at St Louis / Iron Range Resources and 100 at Crow Wing / MN DNR).

$$Y_{ijkl}=\mu + S_i + B_j + F_k + S_iF_k + \varepsilon_{ijkl}$$

Type I variance components were calculated using a reduced model (Proc varcomp, SAS 2004):

$$Y_{ijkl}=\mu + B_j + F_k + \varepsilon_{ijk}$$

Narrow-sense ($h^2_i$) and broad-sense ($H^2_f$) heritabilities were calculated for all traits at each site using the full complement of families at each site (Falconer and McKay):

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

where $\sigma_F^2$ is the variation due to full-sib family, $\sigma_\varepsilon^2$ is the residual variation and R is the number of replications (blocks).

Results

Survival exceeded 85% at both sites (Table 1). At the site in Crow Wing County, mortality was attributed largely to sporadic pocket gopher (*Geomys bursarius*) invasions and moderate to severe gall rust infections (likely *Endocronartium* sp.). In St Louis County mortality was due to infrequent gall rust (likely *Cronartium* sp.) and other non-specific causes. Only 2% of trees died at St Louis County since 2001 while an additional 10% of trees died at Crow Wing from 2001 to 2008. This is likely due to a combination of increased rust infection and additional mortality from pocket gopher. Gall rust infections increased substantially between 2003 and 2008 at Crow Wing County and were difficult to visually assess in 2008 since nearly all trees contained one or more visible galls. Trees were generally taller and had bigger diameters in Crow Wing County than in St Louis County although by a small margin.

**Table 1. Survival, height and diameter data by site (CW=Crow Wing / MN DNR; SL = St Louis Co. / Iron Range Resources).**

| | Survival | | | | Tree heights (m) | | | | DBH (cm) | | Max in 2008 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | 2001 | 2003 | 2006 | 2008 | 2001 | 2003 | 2006 | 2008 | 2003 | 2008 | Ht | DBH |
| CW | 95% | 92% | 89% | 85% | 1.16 | 2.17 | 3.53 | 5.37 | 2.12 | 8.53 | 7.4 | 13.7 |
| SL | 92% | 91% | 91% | 90% | 0.83 | 1.97 | 3.35 | 5.31 | 1.74 | 8.35 | 7.1 | 12.5 |

Analysis of variance was highly significant ($p < 0.01$) for all factors (site and family) and variables measured (ANOVA table not shown). Family by site interaction, a surrogate for genotype by environmental interaction (GxE), varied significantly at different time periods and are shown in Table 2. Significant GxE means that tree ranks for a variable were inconsistent between sites, owing perhaps to differential adaptation by families. GxE was significant for tree heights three years after planting (2001), but was not significant in 2003 or 2006. After ten years of growth (2008) GxE interactions were again significant. A similar trend was observed for diameter at breast height and stem form, with no detectable interaction in the 2003 dataset but high significance in 2008. No significant interaction for cone stature was present. This trait presented itself consistently across sites.

**Table 2. P-values from analysis of variance showing significance of family by site interaction (GxE) for each variable. NS = interaction not significant (p value > 0.05).**

| | Tree heights | | | | DBH | | Form | | Cone stature |
|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 2003 | 2006 | 2008 | 2003 | 2008 | 2003 | 2008 | 2008 |
| Site*Family | <0.01 | NS | NS | <0.01 | NS | < 0.001 | NS | <0.001 | NS |

Heritabilities, shown below, were relatively low for growth traits (height and diameter) and high for stem form and cone stature. Stem form was consistent between sites and assessment years (2003 vs 2008) suggesting that stem form at five years of age was consistent five years later. Broad-sense heritabilities were high and followed the same trends as narrow-sense. Heritabilities tended to be lower at St Louis County compared to Crow Wing likely due to

the greater uniformity of soils at Crow Wing than St Louis. These heritabilities (0.06 - 0.17) are smaller than those reported for first-generation orchards (approximately 0.25, R. Klevorn personal communication). The second-generation estimates in Table 3 are probably more realistic since the assumption of half-sibs is not necessary, and the numerator is half as much (2 instead of 4). The resulting heritabilities from full-sib data tend to be smaller than open-pollinated data.

**Table 3. Heritabilities for 2008 dataset: tree heights, diameter at breast height, volume, stem form and cone stature at each site.**

| | Narrow sense | | Broad sense | |
|---|---|---|---|---|
| | Crow Wing/ DNR | St Louis/ IRR | Crow Wing/ DNR | St Louis/ IRR |
| **2001 Height** | 0.16 | 0.15 | 0.60 | 0.59 |
| **2003 Height** | 0.11 | 0.08 | 0.52 | 0.44 |
| **2006 Height** | 0.15 | 0.06 | 0.59 | 0.37 |
| **2008 Height** | 0.17 | 0.10 | 0.63 | 0.48 |
| **2003 DBH** | 0.12 | 0.06 | 0.54 | 0.35 |
| **2008 DBH** | 0.20 | 0.12 | 0.67 | 0.54 |
| **2008 Volume** | 0.21 | 0.13 | 0.68 | 0.56 |
| **2003 Form** | 0.30 | 0.29 | 0.76 | 0.76 |
| **2008 Form** | 0.29 | 0.32 | 0.76 | 0.77 |
| **Cone stature** | 0.55 | 0.64 | 0.87 | 0.89 |

Family ranks were inconsistent between sites for tree volume owing to the high degree of GxE interaction (Figure 1). Eight families that performed in the top 15% at St Louis County were not replicated at Crow Wing county due to low quantities of available seed or low germination rates of those seedlots. Top-performing families at Crow Wing were only average performers at St Louis County for tree volume.

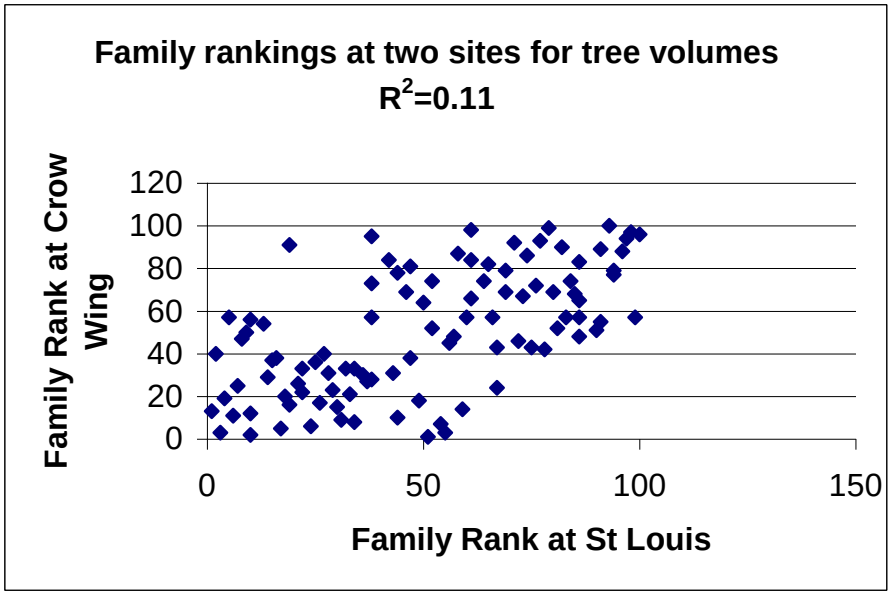


**Figure 1. Family ranks for tree volumes at both sites.**

Cone stature (curled vs straight cones) was divided evenly between trees at each site (Table 5). For cone stature, a numeric value was assigned (1 for curled, 2 for straight) to permit calculation of heritability and analysis of variance. Heritabilities were high (Table 3), no GxE interaction was present (Table 2), and as such this trait correlates strongly between sites (Figure 1). Stem form had significant GxE in 2008(Table 2) but correlated significantly across sites (Figure 2).

**Table 4. Number and percent of trees in each category for cone stature (upright vs curled or no cones to assess) at each site (CW=Crow Wing/MN DNR, SL=St Louis/Iron Range Resources).**

| Site | | Upright | Curled | No cones |
|---|---|---|---|---|
| CW | N | 791 | 723 | 25 |
| | % | 51% | 47% | 2% |
| SL | N | 1318 | 960 | 44 |
| | % | 57% | 41% | 2% |

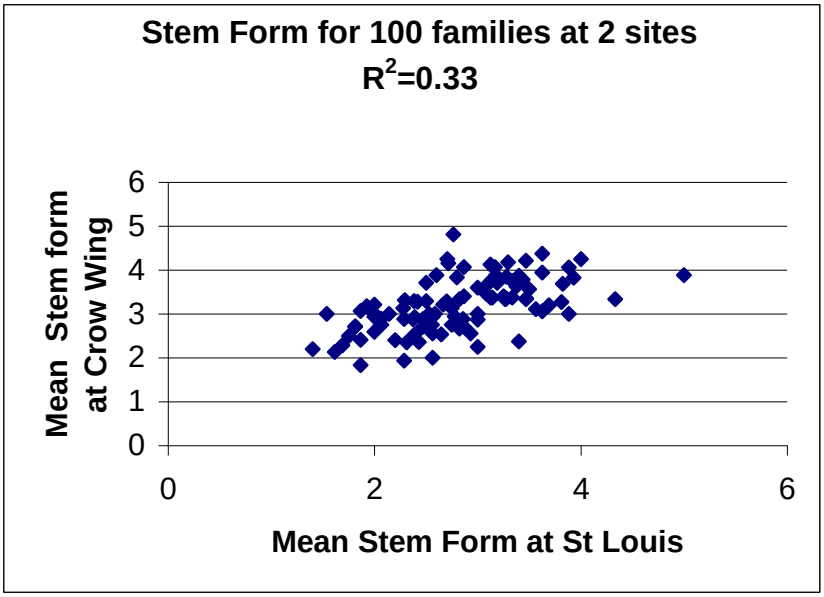


**Figure 2. Stem form at two locations.**

Discussion

Survival was high at both sites. Both sites had undergone extensive site preparation prior to planting and were well-maintained. Mortality at Crow Wing was due primarily to two factors: root pruning by pocket gopher and the presence of gall rust. Nearly all trees showed signs of infection at Crow Wing County, where infections at St Louis County were scarce. A new scale for measuring the incidence of gall rust needs to be developed, and the trees at Crow Wing and St Louis should be re-assessed in 2009.

No significant GxE interactions occurred for growth variables when trees were young but became significant at year ten. Both sites have reached crown closure and the growth of small trees will likely be suppressed. This growth suppression may be part of the GxE interaction that surfaced in 2008. Heritabilities were generally lower at St Louis County than at Crow Wing, suggesting that environmental variation was higher in St Louis County. The soils at St Louis County were highly variable while Crow Wing County was consistently sandy.

GxE interactions were a hallmark of the growth data for tree heights, diameters, and volume (a hybrid of height and diameter). The sites differ slightly in terms of latitude (the planting in Crow Wing County is further south than the planting in St Louis County) but differ profoundly in terms of annual precipitation and ecological classification. (St Louis County is located within the Laurentian mixed forest and the Crow Wing site is located in the eastern broadleaf forest.) These sites also differ in terms of the gall rust populations they foster. Pine-oak rust (*Cronartium quercuum* f.sp. banksianae) is dominant in Crow Wing County while pine-pine rust (*Endocronartium harnessii*) is dominant in central St Louis County (Dietrich et al. 1985). The Crow Wing site is surrounded by oak and pine forest, thus the high incidence of gall rust is not surprising. The severity of GxE interactions precludes a traditional one-size-fits-all approach to the tree improvement program. Families for advanced-generation orchards should be selected carefully, based on performance at each site and not across sites. Two different seed

zones for improved jack pine could potentially be established for the western and the eastern regions of Minnesota.

Stem form was highly heritable and correlated strongly between sites, despite having significant GxE in 2008. The severity of gall rust infections at Crow Wing County resulted in multiple stems from the dieback of main leaders. This changed stem form for trees that were highly infected. Heritabilities for this trait were similar from 2003 to 2008 suggesting that all families were impacted similarly.

Cone stature was first measured in 2008. Only 2% of all trees lacked cones to assess, owing to the prolific and early-flowering nature of jack pine. The high heritability for this trait suggests that trees within a single family produced cones that were either curled or upright, but not both. These patterns were not influenced by site, as indicated by the lack of GxE interaction. Cone stature was not assessed on first-generation orchards, and further analysis would be necessary to determine its genetic dominance among progeny. Cone serotiny (the habit of closed cones) varied within the crowns of each tree and was difficult to categorize. Cone serotiny is highly genetically constrained by origin, and is associated with regions where fires are lethal (Gauthier et al 1996). Cone stature was fairly consistent within a crown and therefore was a good candidate for assessment.

Further investigation on these sites should be conducted to better understand the nature of cone stature, improve calibration of gall rust infection, and to assess branch angle. The tight spacing will require some early roguing, but these assessments could be completed in the summer of 2009. Once this data is completed, a plan for roguing and producing advanced-generation orchards should be finalized.

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**Characterizing growth and variation among families of *Picea glauca* and predictions for productivity in a changing climate**

Progress report on graduate research
By C. Pike

Introduction

Tree improvement efforts in white spruce have combined seed-sources from southeastern Ontario, a region known for producing fast-growing stock, with sources selected from stands in Minnesota and Wisconsin. The potential for genetic gains in improved material is high, however the physiological mechanisms that trigger this extra growth are not well understood. Trees that grow faster may do so by breaking bud early, growing faster during the mid-season, or setting buds later. In white spruce, early bud-break is implicated as the primary mechanism to achieve added growth (Pollard and Ying 1979). In spring, frost damage on white spruce is common especially among families that break bud early (Nienstadt 1984). Flushing-times are highly heritable (Yeatmen and Venktesh 1974) and tree-tree variation for this trait within a natural stand is high (Pollard and Ying 1979; Li et al 1997). Artificially-selected genotypes may foster a heightened propensity to break-bud early, which could increase the risk for widespread mortality in areas that are prone to spring frosts. In pines, photosynthetic capacity is higher in taller vs shorter trees (Marshall et al 2001) supporting the idea that mid-season growth may be the causative factor for added height growth. Unlike pines, white spruce is a determinate grower and therefore less likely to suffer reduced cold tolerance due to delayed growth cessation in the fall. However, the importance of understanding growth habits of genotypes selected for increased height growth is critical toward realizing genetic gains across a region with wide-ranging temperature differentials.

In Minnesota, seed collected from orchards is deployed state-wide; orchards are not specific to a particular seed-zone, or region. The decision to deploy improved seedlings state-wide was based on results from ten-year growth data where little to no significant gxe interaction was found (Klevorn 1995). Analysis from 20-year data revealed that gxe is not significant among families with the fastest growth habits (top-ranking) and slowest growth (low-ranking), however gxe interactions were significant among many families whose growth habit was intermediate. It is possible that top-ranking genotypes are broadly adapted and likely to suffer during extreme weather events that may occur with greater frequency in a changing climate. Given the vulnerability of white spruce to frosts, and the possibility that select top-ranked sources may break bud early, the need to identify families that are adapted to frost-prone areas may become necessary to increase productivity. Mid-ranking families may provide higher genetic gains over top-ranking families where early frosts are common, provided that the mechanism for added growth be based on increased photosynthetic capacity and not early bud break.

The objective of this research is to elucidate the mechanisms that differentiate improved sources, quantify sources of phenotypic variation for a variety of plant traits that contribute to measures of productivity, and investigate the nature of gxe interactions. In addition, a trial using seedlings of improved and woods run material is planned to compare the sensitivity of improved material, vs woods run, to a variety of climatic manipulations. These manipulations may include thawing in mid-winter and refreezing, early spring frosts, and excessive late spring heat.

Combining data from the seedling trial with data collected from middle aged siblings in the progeny test should provide a broad characterization of the tradeoffs that occur when improved seedlings are planted across a variety of sites and climatic conditions.

Proposed methods

In 1986, the Minnesota Tree Improvement Cooperative established an open-pollinated progeny test of white spruce at five locations in Minnesota. A total of 292 families are represented in this trial. Progeny of these families are replicated in as few as three, but sometimes as many as five, locations. Each location was planted in a randomized complete block design with one 4-tree row plot per family per each of five replications. Tree growth was measured at year five, eight and ten at all five sites. In 2000 three sites were thinned to approximately half their size (2 trees from each row plot were removed). At years 15 and 20 tree heights and diameters were measured at three of the five locations. In 2007, a fourth site – MN DNR's Ross Lake north of Aitkin Minnesota – was thinned. Tree heights and diameters were measured at this site in summer 2008.

Survival, heritabilities, age-age correlations, genetic and phenotypic correlations among families will be thoroughly investigated for these four sites. Additional plant-traits – novel to this progeny test – will be collected. These traits will include wood density, leaf nitrogen, needle retention, and specific leaf area for select families representing top, middle and low-ranking families (for growth). Three sites: Finland, Nickerson, and Nine-mile will be used for this analysis. For each trait measured, calculations will include genotypic and phenotypic variation and heritability. Increment cores will be used to quantify family response to past climate, and a sample from select rings will be analyzed for C13 isotopes (which give a measure of sensitivity to seasonal drought).


Figure 1

Dendrobands (photo courtesy of Keeland and Young 1986) will be placed on 20 trees at each of two sites (Finland and Nickerson) in spring 2009. These bands will be used to measure the dates of initiation and cessation of diameter growth among various improved families. Ten trees from each of the top and lowest tiers of growth will be banded. Measurements will be taken frequently in the spring and again in the fall to determine the period during which growth is taking place. This information is valuable since diameter growth often occurs well beyond dates of bud set (J. Oleksyn, personal communication). A tree that delays cessation of growth may demonstrate a heightened sensitivity to early onset of cold weather.

For the seedling trial, seed from 17 improved sources (a combination of full- and half-sib families) were grown alongside three woods run sources provided by the MN DNR Badoura nursery. Seedlings are stored in a 35 degree (F) cooler until spring 2009 and will be subjected to a variety of warming tests to observe response in 2009 and 2010.

Accomplishments in 2008

One tree from each 2-tree row plot (approximately ten trees per family per site) was selected from 30 families at Finland and Nickerson. From each selected tree, one 10-mm increment core was collected at breast height along with one branch sample from the mid-crown.

A second 5-mm increment core was collected at a 90 degree angle relative to the 10mm core from the base of the tree (0.5 meter from the ground). Large (10mm) increment cores were stored in PVC tubes with cork stoppers and processed shortly after for wood density. Small (5mm) cores were stored in straws and later mounted onto boards for tree ring measurements. Tree branches were processed in St Paul to calculate needle area and mass. Wood density calculations were completed at both sites.

Plans for 2009

- Complete calculations for specific leaf area (needle area: dry mass)
- Process needle samples (mince and place into vials) for shipment to an outside lab for Nitrogen analysis.
- Measure tree rings
- Collect wood samples from cores for shipment to outside lab for C13 isotope analysis.
- Collect wood density cores, increment cores, and branch sample from a third location (likely Blandin's Nine-mile)
- Place dendrobands and begin measurements.
- Ship seedlings from cooler in St Paul to Cloquet and Grand Rapids for warming trial. Pot a subset of seedlings into large pots for analysis of root:shoot ratios.

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