ANNUAL REPORT

Minnesota Tree Improvement Cooperative

January 1-December 31

2010

C. Pike, Coordinator
J. Warren, Research Fellow
A. David, Director

FULL MEMBERS
Beltrami County
Cass County
Crow Wing County
Iron Range Resources, Mineland Reclamation
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
Itasca Greenhouse, Inc.
Pine County

Department of Forest Resources
College of Food, Agricultural and Natural Resource Sciences
University of Minnesota

EXECUTIVE SUMMARY

The Minnesota Tree Improvement Cooperative completed its twenty-ninth year in 2010 with thirteen full members and six supporting members. Dues payments in the amount of $62,136 were collected, which included the contract with the Minnesota Department of Natural Resources. During 2010, Andrew David directed the Co-op while Carrie Pike managed day to day activities. Jim Warren provided field and technological assistance, and Egon Humenburger provided field assistance on projects related to white pine. Two business meetings were held: January 15th at the North Central Research and Outreach Center in Grand Rapids, and March 18th at the MN DNR General Andrews Nursery in Willow River. A white pine symposium was held in partnership with the Sustainable Forests Education Cooperative at the Cloquet Forestry Center on January 12 and a field tour was held at Red Lake greenhouse on October 14th.

In 2010, priorities included production of controlled crosses at St Louis County's red pine orchard, collecting data at the second-generation white spruce populations and completing data collection from the 2nd generation jack pine populations. Five-year measurements on the 2nd generation white spruce were completed. Cones were collected from seven different seed orchards. Jack pine and red pine were grafted at Willow River, and white pine was grafted at the forest genetics lab in Grand Rapids.

A warming experiment was conducted as part of Pike's graduate research, and subsequent phenological data was collected during the growing season. Tree diameters were monitored weekly on select trees at two progeny test sites throughout the growing season. The second destructive sampling from the root/shoot study was completed.

In 2011 grafting is slated to take place at the MN DNR Nursery in Willow River, and at the Forest Genetics lab in Grand Rapids. Additional controlled pollinations of red pine are planned. Thinning will continue at both 2nd generation jack pine populations to facilitate cone collections. Grafts will be planted into Red Lake's new red and white pine seed orchards. Site preparations for a white pine disease garden and progeny test are underway. Site preparation towards the establishment of new orchards for MN DNR, Beltrami County, and Crow Wing County is ongoing.

Table of Contents

A LETTER FROM THE DIRECTOR

Dear Cooperative Members,

As you peruse this annual report take a moment to reflect on the amount of work that has been accomplished in the past year and what the cooperative brings to you and your organization. Yes, the Minnesota Tree Improvement Cooperative provides the knowledge to improve tree volumes each generation but it also provides much more. Your cooperative provides up-to-date recommendations on how to manage seed orchards for high seed yields, and low pest and disease incidence. It provides technical support on grafting, fertilization, and sanitation, assists with plantation measurements and then performs data analysis and does the reporting.

In addition, your cooperative fosters opportunities for professional development and networking by arranging, organizing and hosting annual meetings, workshops and seminars that address relevant issues for practicing foresters. Moreover, we are an arm of the University of Minnesota that still does outreach activities visiting each of you at least once a year to review your organization's program.

We are Minnesota's longest running forestry cooperative for good reason – we provide a host of benefits at minimum cost, on a sliding scale, to our cooperators. I challenge you to take advantage of all the cooperative has to offer you.

Finally, a special thanks to Greg Bernu who was instrumental in convincing the Carlton County Board of Commissioners to purchase the former Potlatch seed orchard complex. This ensures that the white spruce and jack and red pine orchards will remain in the cooperative for many productive years.

Sincerely,

Andy David

Andrew David
Associate Professor
Director MTIC

INTRODUCTION

The Minnesota Tree Improvement Cooperative (MTIC) entered its 29th year in 2010 with 13 full members and six supporting members. Accomplishments during the 2010 field season included controlled pollinations at St. Louis County red pine orchard, completing data collection from second-generation jack pine populations, and locating sites for future orchards. In winter 2010, grafters at General Andrews Nursery produced red and jack pine grafts, and white pine grafts were produced at the Forest Genetics laboratory in Grand Rapids. Cone crops were lackluster in 2010, with cones acquired from seven orchards resulting in approximately 57 bushels of cones. White pine grafts were planted into the St Louis County orchard in spring 2010. A white pine symposium was held at the University of Minnesota's Cloquet Forestry Center (CFC) on Jan 12, 2010 in collaboration with the Sustainable Forests Education Co-op (SFEC). This meeting was attended by over 120 people and was extremely well received. Speakers were invited from Ontario, Wisconsin and Minnesota. A workshop was held on Oct 14, at Red Lake's new greenhouse facility, followed by a field tour of their jack pine and white spruce orchards, and future home of red pine and white pine orchards. Fifteen people were in attendance. No registration fees were charged and Red lake provided a wonderful lunch.

In April, Pike passed oral and written candidacy exams toward a PhD in Natural Resources Science and Management at the University of Minnesota. In winter 2010, Pike's graduate project on experimental winter warming commenced. Dendrometer bands, placed in fall 2009 at each of two progeny test sites, were measured weekly throughout the summer. In fall 2010, 60 trees from the root:shoot study were destructively sampled.

Additional selections were made at the Moose Fence site in Tofte, following recommendations from a visiting scientist, Dr. Bro Kinloch. Dr Kinloch is a retired geneticist from USDA Forest Service in California and has worked extensively with blister rust resistance in sugar pine. His visit to Minnesota prompted a flurry of activity at Moose fence site.

This report summarizes activities and accomplishments from January 1 to December 31, 2010. 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 involve MTIC staff or resources, follows the Outlook section. The summaries provided have not been peer-reviewed or published, and thus the results are subject to change upon final analysis.

ADMINISTRATION

The MTIC is coordinated by Carrie Pike, Research Fellow based at the College of Food, Agricultural, and Natural Resource Sciences (CFANS), Cloquet Forestry Center (CFC). Jim Warren, also a Research Fellow, provides technological and field assistance on projects for the MTIC, the white pine blister rust program, and the CFC. Andy David, Director and Associate Professor with the Department of Forest Resources, assists with long-term directives and consultation and is based at the University of Minnesota's North Central Research and Outreach Center (NCROC) in Grand Rapids, MN. Egon Humenburger, also based in Grand Rapids, assists on a variety of MTIC and non-MTIC related projects. Andy serves as Principal Investigator while Carrie coordinates day-to-day operations of the Co-op's finances, communications, reports, data collection and analysis. Jim maintains the Co-op's information databases and serves as technology guru.

The Advisory Committee consists of representatives from each member of the MTIC. It met twice during 2010: January 21 at the NCROC in Grand Rapids, and again on March 18th at the MN DNR's General Andrews Nursery in Willow River.

On-site visits were made to many of the over 40 MTIC plantings by Pike and Warren. Pike contributed two talks, "Climate change in Minnesota" and "Jack Pine in Minnesota: Combining Traditional Tree Improvement with Ecological Classification" at the Northern Forest Genetics Association meeting September 7-9 in at Purdue University in Indiana. The jack pine talk was rehearsed before the Reich Ecology lab group meeting on October 11. Pike also attended the meeting of the North Central Forest Pest working group in Elkhart Lake, WI October 4-7. Pike gave a one-hour presentation on tree improvement to Vermilion College students at the CFC on September 23th and contributed a one-hour talk on "Genetics, climate change and implications for management" as part of the SFEC's climate change seminar series led by Dr. Lee Frelich.

FINANCES

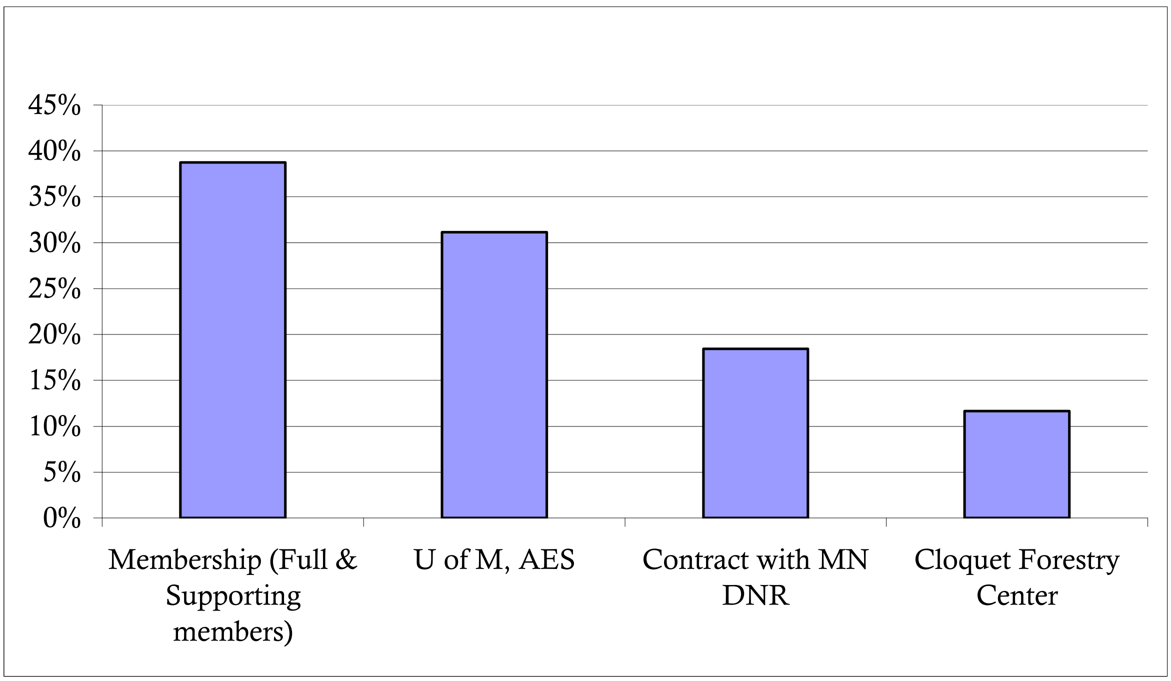
The MTIC is funded primarily from dues paid by public and private forest agencies in Minnesota, Wisconsin, and Michigan. Dues are renewed annually. Dues cover costs associated with staff salary and fringe, supplies, vehicle lease and maintenance, and travel expenses.

Funds remaining in the Co-op's account at the end of the fiscal year are rolled over, and therefore referred to as "carry-forward" funds. Income and expenses are reported on a fiscal-year basis. Dues notices are distributed in November, with payments expected by June 30 of the current fiscal year. A contract with the MN DNR is renewed each biennium (beginning July 1) and covers a portion of Pike's salary and fringe. July 1, 2011 will mark the beginning of the next biennium for the contract with the MN DNR. The University of Minnesota's Department of Forest Resources also provides salary support through the Agricultural Experiment Station (AES).

The White Pine Blister Rust project is primarily supported by the University of Minnesota's AES, as appropriated by the legislature. These funds are used for personnel and supplies pertaining directly to improving the genetic resistance of white pine (*Pinus strobus*) to white pine blister rust (*Cronartium ribicola*). It covers a portion of Pike, Warren, and Humenburger's salary for work pertaining to white pine blister rust research. Beginning in FY10 AES white pine funds will no longer fund histology work for white pine blister rust research at the Pathology laboratory directed by Dr. R. Blanchette.

Nineteen organizations (including the Minnesota DNR) paid dues in 2010, resulting in $62,136 in dues collected. Dues in 2010 were less than budgeted for several reasons. In 2010, MNLA did not renew supporting membership. They will be contacted in FY11 for future renewal. Potlatch reduced their dues in FY10 by approximately 12%, a reduction that was implemented on all tree improvement memberships to which Potlatch belongs. Itasca Greenhouse paid dues at the supporting member level.

Figure 1. Income sources for Minnesota Tree Improvement Cooperative during FY10 by membership type (July 1, 2009 through June 30, 2010).



SEED ORCHARDS

Seed is the "currency" of a tree improvement program. Seed orchards are the means by which improved seed is produced for reforestation. Each full member in the MTIC takes charge of site preparation and management of at least one orchard. Orchards are in place for six conifer species. The MN DNR has the largest number of orchards, with fourteen actively managed for seed production, one of which is a collaborative effort with Crow Wing County. 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 orchard) was marked in 2008 for roguing but is only partially completed. New improved-first generation orchards for white spruce are being developed. A summary of the types and sizes of orchards is shown in Table 1. Tables 2 & 3 list all orchards by species and owner for *Picea*, *Pinus* and *Larix* respectively. All "research" trials are listed in Table 4. A research trial is intended for data collection but is generally not designed for seed production. Second-generation jack pine populations are listed as "research" trials until they are thinned and are then managed for seed collection and tree breeding. Cone collections made in 2010 are shown in Table 5.

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 spp* seed orchards actively managed by the MTIC.

Species	*Orchard Type*	*Organization*	*Date Planted*	*Size (ac)*	*Live Trees*
Black spruce	1st Gen. Clonal	Koochiching County-B	19-May-89	2.3	61
		Koochiching County-L	27-May-98	4.0	59
		Minnesota DNR	01-May-79	1.3	812
	1st Gen. Seedling	Minnesota DNR	17-May-78	2.7	582
		Potlatch Forest Holdings, Inc.	01-May-78	3.0	580
		Blandin Paper Company	22-May-78	2.5	596
	2nd Gen. Seedling	Minnesota DNR	27-May-92	2.4	262
		U of M CFC	01-May-95	1.1	238
			8 Orchards	***19.3***	***3,190***
White spruce	1st Gen. Clonal	Itasca County	02-Sep-87	1.1	175
		Lake County	02-Sep-87	1.0	198
		Minnesota DNR	01-May-77	12.0	206
		Potlatch Forest Holdings, Inc.	01-May-77	3.3	140
		St. Louis County	11-May-88	1.5	189
		UPM-Blandin 'A'	01-May-76	1.5	121
	1st Gen. Seedling	UPM-Blandin	15-May-67	4.1	224
	1-1/2 Gen. Clonal	Minnesota DNR	02-Sep-01	3.7	255
		Carlton County	01-Apr-03	2.1	187
		Red Lake	01-Apr-04	0.9	157
		UPM-Blandin 'C'	05-Sep-00	2.9	780
	2nd Gen. Seedling	Lake County	06-Jun-05	1.3	818
		Itasca County	20-May-03	1.8	693
		Minnesota DNR	03-Jun-03	1.8	401
		Minnesota DNR	01-May-05	1.3	764
		St. Louis County	06-Jun-03	2.1	393
		UPM-Blandin	01-May-05	2.4	900
			17 Orchards	***44.8***	***6,601***

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

Species	*Orchard Type*	*Organization*	*Date Planted*	*Size (ac)*	*Live Trees*
Jack pine	1st Gen. Seedling	Cass / Beltrami/ Hubbard Counties	08-Oct-82	3.4	492
		Crow Wing County	04-Jun-85	2.1	247
		Iron Range Resources	16-Sep-82	1.7	220
		Minnesota DNR-E	18-May-84	4	465
		Minnesota DNR-L	15-May-84	2.4	387
		Carlton County	28-Jun-83	5.5	183
		Red Lake Nation	29-Apr-87	1.8	516
		St. Louis County	10-May-88	1.6	279
	2nd Gen. Seedling	Crow Wing Co. / MN DNR	01-May-99	2.6	1264
		St. Louis / Iron Range Resources	12-May-99	3.8	2064
			10 Orchards	***28.9***	***6,117***
White pine	1st Gen. Clonal	Itasca County	19-May-98	5.7	498
		Itasca Greenhouse	16-Jun-05	0.8	401
		Minnesota DNR- 'S'	25-May-93	1.0	88
		Minnesota DNR- 'Z'	15-May-85	3.0	319
		St. Louis County	02-May-90	1.1	233
		St. Louis County-E	21-Jun-99	2.5	237
			6 Orchards	***14.1***	***1,776***
Red pine	1st Gen. Seedling	Cass / Beltrami/ Hubbard Counties	10-Sep-91	5.3	400
		Minnesota DNR-C	29-Jul-81	4.5	462
		Minnesota DNR-E	25-Jun-81	3.6	128
		Carlton County	10-Jul-81	6.6	461
		St. Louis County	09-May-88	5.5	531
			5 Orchards	***25.5***	***1,982***
Tamarack	1st Gen. Seedling	Minnesota DNR	12-May-08	4.3	2,005
			1 Orchard	***4.3***	***2,005***

Table 4. Research trials planted by the MTIC.

Species	*Planting Type*	*Year planted*	*Organization*	*Last measured*	*Next Scheduled*
Black spruce	Full-sib progeny test	1995	U of M	1995	--
	Comparison trial	2008	Koochiching County	--	2011
White spruce	Comparison trial	1993	Minnesota DNR	2002	2012
		1993	Plum Creek Timber Company	2002	2012
		1993	Potlatch Forest Holdings, Inc.	2002	2012
		1993	Blandin Paper Company	2002	2012
		1995	Potlatch Forest Holdings, Inc.	2000	--
		1995	U of M	2005	2015
		2003	Koochiching County	2007	2012
		2003	Minnesota DNR	2007	2012
		2003	Potlatch Forest Holdings, Inc.	2007	2012
		2003	St Louis County	2007	2012
		2003	UPM-Blandin	2007	2012
	Progeny test	1986	Lake County	2005	2015
		1986	Minnesota DNR 'N'	2005	2015
		1986	Minnesota DNR-'R'	2008	2015
		1986	St Louis County	2005	2015
		1986	UPM-Blandin	2005	2015
	2nd generation population	2003	Itasca County	2007	2012
		2003	St. Louis County	2007	2012
		2003	Minnesota DNR	2007	2012
		2005	Lake County	2010	2015
		2005	Minnesota DNR	2010	2015
		2005	UPM-Blandin	2010	2015
Jack pine	2nd generation population	1999	St Louis / Iron Range Resources	2008	--
		1999	Crow Wing / Minnesota DNR	2008	--
Red pine	Comparison trial	2007	Beltrami County	---	2011
		2007	Potlatch Forest Holdings, Inc.	---	2011
		2007	U of M	---	2011
		2007	St Louis County	---	2011
White pine	Progeny test	1999	St Louis County	2008	--
		1999	USFS	2008	--
		1999	ORSO	2008	--

Table 5. Cones collected by MTIC members in 2010.

Species	*Agency / Industry*	*# bushels*
Black spruce	Koochiching Co.	1
Jack pine	MN DNR-L	40.0
	MN DNR-N	1.0
	Crow Wing	10.1
	Crow Wing / MN DNR	3.1
	Red Lake	1.0
White spruce	Red Lake	1.0
Total number of bushels collected		57.2

SPECIES REPORTS

Black spruce

Status

Cone crops were moderate in black spruce this year. Another crop, 2 bushels, was secured at Koochiching County's 'B' orchard. Koochiching 'L' orchard is monitored for cone crops and mowed several times annually. Both orchards produce small annual crops that are easily accessible from the ground. A moderate crop was also found on Blandin's orchard but was not picked this year. The MN DNR maintains two orchards, a second-generation near Moose Lake and a clonal orchard near Sturgeon Lake. A large crop was picked from the DNR second-generation in 2009. The trees at DNR clonal orchard are large and would require a lift to access cones. No cones to date have been picked from this orchard.

Short and long-term planning

Orchards remain in good condition and will continue to be managed for seed production. The black spruce comparison trial planted in 2008 in Koochiching County will be visited in early spring 2011 to assess survival. The site was visited this summer and survival was sufficient to merit a survey in early spring. The planting will continue to be monitored for growth and survival. Koochiching County also plans to fill in approximately 20 empty spaces at the 'B' orchard with white spruce grafts, to provide a source of improved seed for planting on skidder trails and landings created from harvests.

White spruce

Status

White spruce cones were generally absent in MTIC orchards in 2010. The St. Louis County orchard produces small crops annually, along with periodic bumper crops. Most of the large trees were topped in the fall of 2007. Replacement grafts are well established. Blandin's clonal orchard 'C' posted a remarkably sparse crop this year, following two consecutive years of bumper cones. A modest cone crop was observed at Blandin's 'A' orchard but cone were not picked. Cone crops at MN DNR and Lake County's grafted orchards were small, although the DNR clonal orchard was topped and picked in 2009, so the absence of cones was no surprise. Blandin's seedling-seed orchard is no longer used as a seed orchard and is for sale. Grafts at Red Lake's orchard have begun producing small crops and remain in excellent condition. The Potlatch orchard was in 2010 and was eventually obtained by the Carlton County Land Department. The young grafts at the improved-first generation orchard there will require some routine maintenance in upcoming years to favor their establishment.

Short and long-term planning

MN DNR, Blandin-A and L are all nearing the end of their productive life. Intensive maintenance of Blandin's newest orchard has resulted in large quantities of seed for their reforestation program. Lake County has expanded their orchard and is ready to add additional grafts as they are made. The Carlton County Land Department now owns the Potlatch orchard, and will begin management activities in 2011. Future grafts will be added to the existing white spruce orchard, which was first planted in 2005. Plans for a future orchard complex of a variety of species for the MN DNR are being made, but a site has not been finalized. The second-generation plantings (planted in 2005 at MN DNR's-E, Lake County, and Blandin sites) will be measured at 5-year intervals. The Koochiching County land Department has plans for adding a small white spruce orchard to the back end of the existing B-black spruce orchard. Soil was tested at the University of Minnesota's soil lab in 2010, and Tom Toratti prepared a small area for planting a few grafts to test their success. Finally, leftover seedlings from Pike's graduate research project were planted in an existing "String of Pearls" site on Blandin land north of Grand Rapids. This site consisted of five different clearcuts in a middle-aged aspen stand. Each cut area, approximately 1 acre each in size, was planted with two 36-tree blocks of each of two sources, "improved" and "woods run" sources. The objective is to compare the growth of woods run and improved sources in these partial-shade conditions. The sites were visited in late fall 2010 and will be permanently monumented in 2011. Kudos to Quintin Legler for his help in coordinating this project!

Jack pine

Status

Cone crops were generally above average in 2010. Forty bushels of cones were collected at MN DNR's 'L' orchard by staff at the nearby Badoura Nursery. Twenty trees were removed from the MN DNR 'N' orchard to ease crowding. Approximately one bushel of cones was collected from the tops of the fallen trees. A spotty crop was observed at Iron Range Resources and was not collected. Cass, Beltrami and Hubbard County's joint orchard remains rough and fairly inaccessible for management in spite of recent efforts to clean it up. Crow Wing County's aging first-generation orchard is still producing cones and remains accessible for management. The former Potlatch jack pine orchard a posted a midsized crop, but was not picked. Red Lake's orchard survived a grass fire thanks to the successful establishment and maintenance of a fire-break. A modest crop was observed in 2010, and one bushel of cones was collected. St Louis' orchard is nearing the completion of its usable life, being replaced by the 2nd generation site in the adjacent fenced area. Pike and Warren collected cone and rust data at the two second-generation jack pine plantings, Crow Wing Co/MN DNR's, and St Louis Co/Iron Range Resources. As these sites will be used as a source of scion for future grafted orchards, topping will be restricted until future ortets are identified.

Short and long term planning

Data collection on the second-generation population is now complete, and the sites will be gradually thinned to facilitate seed production. Selections, however, have not been completed so no topping is planned for the immediate future. The site at St Louis was marked in late fall 2010 for a light roguing. The site at Crow Wing will be marked and thinned in 2011. These sites will also be used for making controlled crosses in the future.

Sixty-five jack pine grafts produced at the DNR's General Andrews Nursery were planted alongside the second-generation trees (within the fenced area) at Crow Wing/MN DNR's site in spring 2010. Jack pine is slated for grafting in 2011 at General Andrews nursery. The resulting grafts will be planted into the new site within a few months of grafting and should complete the improved second-generation orchard. It is expected that survival of "fresh" grafts will exceed survival of those that languish in the shadehouse for an extended period of time.

Efforts to regenerate jack pine have been hindered in recent years by deer browse and competition. In response to these challenges, the MTIC and the SFEC are collaborating once again, this time for a jack pine symposium slated for January 18, 2011 at the CFC.

Red pine

Status

Cone crops in 2010 were highly variable across the state. No cones were harvested from either MN DNR orchard. Last year's crop was the highest at the DNR- 'E' orchard. The 2nd year cone crop at St Louis was low. We expected this since last year's attempt at tree breeding was foiled by the lack of new cones. The cone crop was modest at Potlatch's orchard, but the orchard was sold during the summer and the new owner, Carlton County, was not able to manage it this year.

Roguing at Cass-Beltrami-Hubbard County orchard is temporarily on hold until a contractor can be located. Plans are being made to establish a new red and jack pine orchards in Cass County. The red pine on the site is being removed after recently being vandalized.

Forty-nine controlled crosses were completed by Pike and Warren at St. Louis County's orchard this spring. Seed from these cones will be banked for two purposes: a second-generation population, and a study to measure the effects of inbreeding on red pine growth. A total of 20 full-sib crosses, generated through positive assortative single-pair mating, are planned for the second-generation population. In 2010, 19 crosses were completed, but due to low female flower counts, additional seed will be needed from each cross.

Short and long-term planning

First-generation orchards will continue to be thinned to ease spacing constraints so that trees don't self prune above the reach of a ladder. At DNR-E, 134 trees were marked for permanent maintenance in the future. All unmarked trees should be removed, coinciding with bumper cone crops. The increased spacing at this and other orchards should enhance the frequency and intensity of crops in the future, and facilitate the use of large equipment to pick cones. Thinnings are planned for MN DNR-C, and St Louis' orchard. Tree breeding will continue at St Louis until all crosses are completed. One more cone year will hopefully do the trick.

The MN DNR prepared 500 rootstock for grafting in 2011. Scion will be collected from either MN DNR, St Louis, or Carlton, depending on winter access. Red Lake has completed site preparation for a new improved first-generation red pine orchard. Grafts produced in 2011 will be planted into Red Lake's new grafted orchard in early spring 2011.

White pine

Status

No white pine cones were harvested in 2010. Red Lake completed site prep for a new white pine and red pine orchard. A few cones were present at the St Louis orchard, and additional grafts (Tofte clones) were planted in spring 2010 at the St Louis-E. No cones were observed at MN DNR orchard. Moose Fence white pine in Tofte also had a sparse cone crop.

Ahead of Dr. Kinloch's visit (Introduction, page 4), trees at Tofte were reflagged by Humenburger and David. At the Forest Genetics lab in Grand Rapids, white pine rootstock for 2011 grafting were prepared and seedlings for the future disease garden were germinated. Humenburger visited and re-tagged a white pine research planting in Duluth (Ahlgren's planting, sits adjacent to a RC field). Humenburger and David also recorded periodic phenological development of a white pine provenance trial (established in 2000 by Dr. Paul Anderson, USDA Forest Service) in Eveleth and ORSO.

Short and long-term planning

Grafts remain at the General Andrews nursery in Willow River and Red Lake for planting in 2011. Additional selections made at the Moose Fence property will be grafted for inclusion at the Cloquet breeding arboretum and ORSO in 2011 and 2012.

Plans will be made in winter 2010-2011 to continue screening clones from the CFC breeding arboretum using the electron microscopy technology provided by Dr. Bob Blanchette and Todd Burnes. Plans for a future disease garden are discussed in the Appendix, and a progeny test is also slated for 2013 to quantify fast-growing sources for orchards. Ten year survival and tree heights from Zambino's 1999 progeny test are reported in Appendix B. This study was described in more detail in the 2004 Annual Report of the MTIC.

In recent years, staff at the USDA Forest Service's Oconto River Seed Orchard have been fine-tuning methods for screening eastern white pine seedlings for resistance to blister rust disease. Families that were screened in 2009 and 2010 are shown in Table 10. No results are available to report yet, as data collection is not completed. Seedlings inoculated in 2009 were planted to a site adjacent to the greenhouse, and continue to be monitored for survival. The seedlings inoculated in 2010 represent the pool of families replicated in the USDA Forest Service white pine progeny test, established by retired Forest Geneticist Dick Meier and measured by U of M staff (Pike, Warren and K. Haiby) in 2003 and 2004 (reported in the MTIC Annual reports in 2004 and 2005).

Table 10. White pine families inoculated in 2009 and 2010 at the USDA Forest Service Oconto River Seed orchard.

2009	2010
MI-59	ON-2
MI-47	ON-4
MI-30	ON-70
MI-63	ON-549
MI-46	ON-466
MI-16	ON-469
MI-67	ON-477
MI-111	ON-491
MI-100	ON-492
MI-112	ON-500
MI-40	ON-504
MI-27	ON-516
MI-117	ON-519
MI-25	ON-538
MI-69	ON-615
MI-49	ON-624
MI-105	ON-638
H-111	ON-644
P-327	ON-645
	ON-646
	P-18
	P-30
	P-312
	P-327
	P-343

Key: P- trees were selected by Dr. Robert Patton, UW-Madison. P-327 is included as a resistant control. ON- selections were made in Ontario. H- trees were selected by Dr. Carl Heimburger from Ontario. H-111 is included as a known susceptible control. MI- selections were made from Minnesota (not Michigan).

OUTLOOK

The economy in 2010 remains weak and the University of Minnesota continues to search for cost savings, resulting in changes in the AES funding structure. In addition, membership in the MTIC is expected to drop precipitously in 2012 with the loss of two industries, Potlatch and Plum Creek Timber Company. The contract with the MN DNR is expected to be renewed in 2011 for another biennium. Warren's appointment as Safety Coordinator and IT assistant with the Cloquet Forestry Center is expected to continue into the foreseeable future. Collaborative work on white pine with the USDA Forest Service Regional Geneticist and Manager of Oconto River Seed Orchard continues. New genotypes at Tofte have been identified, and greenhouse inoculations continue for the second consecutive year. Electron Microscopy work on white pine needles is expected to be restarted in 2011 to quantify variation among seed sources with respect to needle traits, primarily wax occlusion.

The need for improved jack pine seedlings for reforestation remains high. A combination of lack of fire, deer browse, and budworm will continue to challenge trees of all age classes. To address these challenges, a symposium is planned for January 18, 2011 at the Cloquet Forestry Center as a collaborative effort between the Sustainable Forest Education Cooperative and the Minnesota Tree Improvement Cooperative.

Grafting for 2011 will take place at MN DNR General Andrews Nursery on jack and red pine, and at NCROC for white pine. In addition, staff at the Oconto River Seed orchard prepared rootstock for grafting selections from the Tofte Moose Fence planting (white pine). New orchards are slated for the Red Lake Indian reservation (white pine, red pine), Crow Wing/ MN DNR (jack pine), and eventually Beltrami County (red pine, jack pine) Tree breeding (red pine) that was initiated in St Louis county will be completed in the next few years pending availability of first-year conelets. Thinning at the 2nd generation jack pine populations will begin, a year later than promised, and cone collections have commenced at both sites. All orchards will be visited to monitor cone crops and management needs.

2011 Cooperative Work Plan

Black spruce
April 2011: conduct mortality survey of black spruce comparison trial planted in Koochiching County near Franz Jevne S.P.

White spruce
Plant white spruce grafts (assorted improved clones) into Koochiching County's orchard.

Jack pine
Plant grafts into CW/ MN-DNR improved 2nd-generation grafted orchard
Marking and thin 2nd generation populations

Red pine
Plant grafts into Red Lake orchard
Finish controlled crosses at St Louis County

White pine
Plant grafts into white pine orchard at Red Lake
Complete site preparation at disease gardens located at CFC and Hubachek Wilderness Research Center in Ely.
Locate two sites for future white pine progeny test
Send needles to Blanchette for screening

APPENDIX

A. Project Proposal: White Pine Germplasm Trial – Disease Gardens

By Andy David & Carrie Pike

Introduction

White pine blister rust disease entered North America in the early 1900s and remains a barrier to the successful regeneration of 5-needled pines in many regions. For over 100 years tree improvement efforts to select and breed for resistance have met with little fanfare owing in part to the complex relationship between a heteroecious fungus and its host. Extensive progeny testing failed to demonstrate reliable transmission of disease resistance from parent to progeny. Over time, blister rust program dissipated with little demonstrable progress made towards the development of resistant seed. *Ribes* eradication became the hallmark of the CCC program in the early 1930s. Unfortunately, baseline data on levels of rust prior to the removal wasn't taken so the success of the program was never fully quantifiable. Today, only a handful of genotypes have repeatedly demonstrated putative resistance.

In recent years, technological advances have enabled scientists to observe the interaction between host and parasite more closely. Research conducted by Dr. Bob Blanchette and his students revealed remarkable divergence in resistance among one year old seedlings that were inoculated and screened in the greenhouse for up to 90 weeks. However, artificial inoculations challenge subject trees with an unnatural spore load that may overestimate resistance necessary for the establishment of successful field plantings. Instead, a combination of laboratory screenings with measured field resistance may provide an opportunity to develop an effective population of genotypes for planting in moderate to high-risk areas.

In 1999 a progeny test was established by members of the Minnesota Tree Improvement Cooperative in collaboration with the USDA Forest Service (see Appendix E). This trial was replicated at four sites to test field resistance of seed sources that performed well in greenhouse inoculations. However, *Ribes* populations adjoining those sites were low and sites were not suited to the inter-planting of additional *Ribes* to bolster disease incidence. A new disease garden approach, in which natural levels of innoculum are enhanced through more careful quantification of local *Ribes* populations and interplanting as necessary, could provide sufficient data to compare resistance among families and between parents and offspring. This effort would complement existing greenhouse inoculations that are being conducted at ORSO. The ultimate goal of any tree improvement project is to capture and transmit genetic gains for commercial reforestation efforts. By disentangling the mode of resistance transmission between parent and offspring, a method to mass-produce seedlings can be undertaken. Three modes of seed production may result, in descending order of production costs: clonal forestry (rooted cuttings), control-pollinated seedlings (produced through mass-controlled pollinations at an established orchard), or open-pollinated seedlings. Seed would be targeted for reforestation along Minnesota's north shore or other areas where blister rust remains a formidable limitation to white pine regeneration. In areas where blister rust is less prevalent, a program to enhance growth rates is being developed through traditional progeny testing and orchard production.

The goal of the disease gardens is to compare resistance of parental genotypes (as grafts) and progeny (as seedlings) from a variety of families to assess the potential for resistance to white pine blister rust. Two sites were selected for their potential to support naturally high sporeloads that could be supplemented through additional *Ribes* inclusion. Seed sources that have demonstrated 'resistance' (defined by Dr. R. Blanchette and here as survival greater than the negative control) and susceptibility would serve as appropriate controls as grafts and open-pollinated progeny. The advantage of using both grafts and seedlings is that it will allow us to see for the first time how parents and progeny perform on the same site simultaneously. A comparison of seedlings to grafts was attempted in earlier work (Ahlgren, 1955) but that work did not compare parents to offspring. Once parent to progeny resistance is understood, this method would be used to develop a model for mass-producing seedlings for commercial reforestation in high-risk areas.

Four hypotheses will be tested:

1. Survival of parents (grafts) with known resistance is greater than parents with known susceptibility.
2. Survival of open-pollinated offspring from parents with known resistance is higher than open-pollinated control seedlings from DNR Seed Zone 104.
3. Survival of control-pollinated families produced from parents that each possess known resistance is higher than open-pollinated crosses of the same parents.
4. Survival of control-pollinated families produced from two resistant parents exceeds any susceptible or control family.

Material

The following sources are proposed for this project:

- 10 genotypes will be grafted at the Forest Genetics lab in Grand Rapids MN.
    - 8 with putative resistance
    - 2 susceptible controls
- 11 open-pollinated families
    - 8 with putative resistance
    - 2 susceptible controls
    - 1 seedlot from the MN DNR, Zone 104
- 7 control-pollinated families
    - 1 cross where both parents are highly susceptible
    - 5 crosses where both parents have putative resistance

A total of 460 trees will be planted at each of two sites at a spacing of 8 x 8 ft.

Proposed Timeline

2010

- Rootstock for grafts was potted at Forest Genetics Lab
- Seed was obtained and germinated at Forest Genetics Lab
- Trial sites were located on University of Minnesota property at Cloquet and Ely.

2011

- Site preparation will be completed at both sites
- Pin flags will be placed at each planting location.
- Secure a source of Ribes to plant within rows.

2012

- Trees will be planted in May
- Local *Ribes* populations will be surveyed within 500 ft of the plantings on all sides.
- *Ribes* will be planted within planted rows.
- Sites will be monitored at least twice before winter 2012.
- Trees will be budcapped or caged.

Literature cited

Ahlgren, C. 1955. Grafted selections of eastern white pine tested for resistance to blister rust. J. For., 53 (10): 727-729.

B. White pine research update

A. David

WRF Research

The MTIC is in the midst of a three year grant from the Wilderness Research Foundation to advance white pine blister rust resistance in Minnesota. Our goals for this project are 1) recreate the more resistant white pine families from the Ahlgren's research for incorporation into a more stringent screening program, 2) test the hypothesis that the increased survival of seedlings when P327 is used as a parent is due to the presence of occluded stomates that act as a physical barrier to blister rust hyphae and 3) graft 50 so called 'slow rusting' phenotypes from the Tofte, Moose Fence planting into our breeding arboretum. This past year we have made substantial progress on all three of these objectives.

Earlier MTIC work involved measuring survival and growth of older Ahlgren progeny trials. From this work we identified particular families that appeared to survive better than others under varying blister rust risk scenarios. Our goal to recreate these crosses so that the seedlings could be screened in a more controlled environment met a major obstacle when the condition of the parental trees was assessed at the Fall Lake seed orchard. The close spacing at the Fall Lake orchard means that the crowns are small and unlikely to create cones except in the very best of cone years. This realization means that first we need to graft trees of interest out of this orchard before we can breed them. In preparation for grafting the Fall Lake orchard, as well as the RC Field in Duluth, were remonumented to make identification of individual trees possible before grafts are collected in spring of 2011 or 2012.

One of the success stories of the search for blister rust resistance in eastern white pine has been P327. This parent produces seedlings that survive greenhouse screening trials at percentages significantly higher than controls. Previous research by Dr. Jason Smith indicated that greenhouse grown grafts of P327 have obvious occluded stomates and the inheritance of this trait has been theorized to be the source of the increased seedling survival. To test the theory that field grown seedlings would also have these occluded stomates we analyzed the stomates from surviving trees of a P327 cross and seedlings from a cross with low survival for comparison. We expected to find occluded stomates at a higher percentage among the P327 seedlings than the negative control but instead found that there was no demonstrable difference between the two groups, neither having obvious, occluded stomates (Figure 1.)

The lack of occluded stomates on progeny of P327 was surprising because it raises questions about occluded stomates as a mechanism of blister rust resistance, and the potential differences between greenhouse grown and field based seedlings. It is interesting to note that the high rate of survival that P327 progeny enjoy in greenhouse screening trials did not hold for the only known long-term field trial which compared several open-pollinated white pine families. In this field trial survival for the P327 family was higher than the average of the trail but was surpassed by other families.

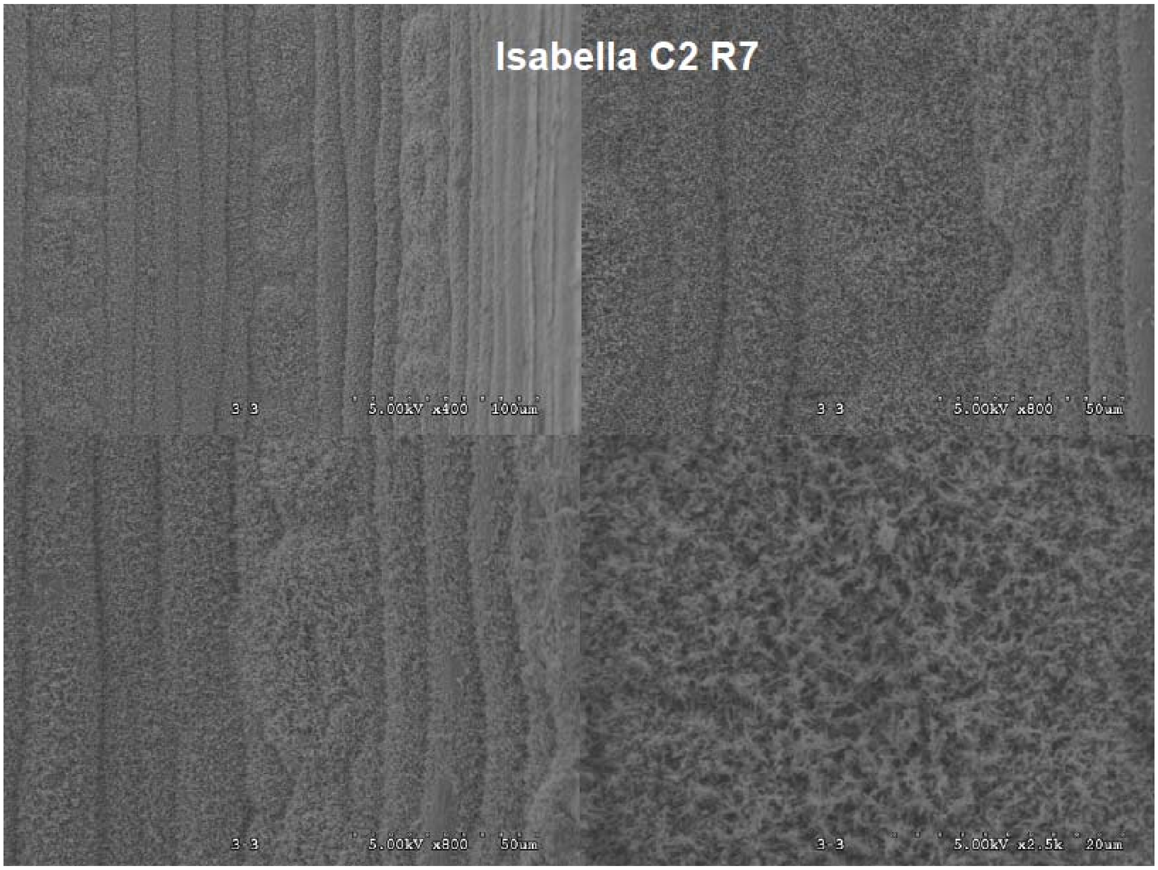


Figure 1. Scanning electron microscopy of white pine needles from an individual tree at the Isabella white pine progeny trial. The four different quadrants are clockwise from upper left, 400x, 800x, 2,500x and 800x magnification. Non-occluded stomates are visible as a chain of ovals.

The Tofte Moose Fence planting was designed to eliminate individual white pine with low levels of resistance to white pine blister rust and leave individuals that were resistant or had increased levels of resistance. Although it has accomplished this goal we know that trees that are free of rust do not necessarily produce rust-resistant progeny. These so called ‘escapes’ were never challenged with blister rust and therefore never contracted the disease. The fact that many of these trees are ‘escapes’ is reinforced every time we rescore the trees at Tofte and find that additional trees that had been free of blister rust are now either severely infected or dead from rust. Recognizing that blister rust is a permanent facet of the landscape we have begun to search for slow rusting phenotypes among the Tofte survivors. These slow rusting phenotypes represent individuals that have been infected with the disease but have coexisted with it for several years, if not decades, and demonstrate physical traits such as inactive cankers or linear cankers with obvious, active callus around the margins.

In conjunction with the USDA Forest Service Oconto River Seed Orchard we revisited all living white pine in the Moose Fence planting in August 2010 and rescored all but those near death for vigor, rust, number of cankers, percent bole alive and presence or absence of callus. Through our efforts we have identified 114 slow rusting phenotypes for potential grafting. The top 50 – 100 individuals will be grafted in the spring of 2011 or 2012 and added to the breeding arboretums at ORSO and the Cloquet Forestry Center.

White pine phenology

In addition to the research we have undertaken with the Tofte material we assessed phenology traits in a 69 family regional white pine open-pollinated provenance trial. This trial was initially started by Dr. Paul Anderson (USFS Pacific Northwest Station) in 2003 to assess adaptive traits in white pine from Minnesota and western Wisconsin. In cooperation with Dr. Anderson and the USDA Forest Service at ORSO we created a photo guide to eastern white pine phenology stages and then assessed bud break phenology at two trial sites near Eveleth, Minnesota and Langlade, Wisconsin during the spring of this year.

Phenology values were taken at 7-10 day intervals during May and June by different crews at each location using the same photo guidebook. Phenology stage 1 through 9 was assigned based on the status of the terminal bud from an uninfected, undamaged stem (Table 1). Although the results are preliminary in that they do not span the entire range of stages in phenological development the scores are remarkable for their consistency. The standard deviation is remarkably small, and the range notably narrow despite 69 families and 2,223 individual trees at Eveleth and 66 families and 1,648 trees at ORSO. The small standard deviation and narrow range suggests there is little difference in phenological development among the families across a wide portion of Minnesota and western Wisconsin.

Table 1. Phenology scores for white pine trees at a) Eveleth, Minnesota and b) Langlade, Wisconsin (Oconto River Seed Orchard).

a) Eveleth	21 May	28 May	4 June	14 June
mean	5.1	6.8	6.9	7.0
standard deviation	0.32	0.50	0.27	0.07
range	4-6	4-7	5-7	5-7

b) Langlade	27 May	1 June	8 June	15 June
mean	5.1	6.9	7.0	7.0
standard deviation	0.29	0.31	0.07	0.02
range	5-6	5-7	6-7	6-7

C. Results update: 2^{nd} generation jack pine population

By: C. Pike

This information is updated from the 2008 annual report where this data was first reported.

Abstract

The MTIC's full-sib second generation population was planted onto two sites in 1999. Tree heights were measured after 3, 5, 8, and 10 growing seasons. Tree diameters and stem form were also assessed after 10 years. Cone serotiny (open vs closed), cone stature (straight vs. curled), and gall rust was sub-sampled after 11 growing seasons. A high level of family by site interaction occurred for volume growth. A significant genetic correlation between cone serotiny and volume growth indicated strong ecotypic associations. As a result, future orchards will be produced from two different populations. The top performing families at the Crow Wing County site will be selected for orchards in west-central Minnesota. Top performing families from the St Louis County site will be selected for deployment in north-east Minnesota. Families selected for fast-growth at each orchard also positively correlate with stem form and low disease incidence. Existing floristic regions of fire-dependent woodland systems are proposed for use as seed zone boundaries.

Introduction

The MTIC's jack pine program began in 1974 with the establishment of the Kallstrom seedling-seed orchard on Potlatch land. Since then, ten orchards have been established and nine are actively managed for seed production. Demand for improved seed is slated to increase as reforestation efforts are revved up following years of defoliation by jack pine budworm and deer browse on young stands.

A second-generation population was necessary to advance orchards and sequentially increase genetic gains from first-generation seedling-seed orchards. Tree breeding efforts towards this goal were undertaken in 1993 and completed in 1997. Over two hundred full-sib, unrelated crosses were produced from seven different seedling-seed orchards across Minnesota. Each orchard contained seed sources that were unique to that orchard, along with sources that were replicated at other orchards. For each family the origin of the original parent tree from which the family was derived was recorded. This data included latitude, longitude, township, range and section for each initial plus-tree that was selected. The floristic region (for fire-dependent woodlands) of each original parent was identified as belonging to the northern, central, or southern regions (MN DNR, 2003).

At each orchard, families were ranked based on their breeding values, calculated using total height measurements at each orchard (Klevorn, unpublished). The mating pairs were determined using positive assortative mating. At each orchard, the tallest individual tree from each of the top fifty families were selected for mating at each orchard. No family was used at more than one orchard. Seed was stored in a refrigerator until all crosses were completed.

Methods

In 1998, seed was germinated at the Iron Range Resources growth chamber. In May 1999, trees were tagged individually using paper labels and sorted by site into boxes. Seedlings were planted in May 1999 at two sites, one each in St Louis and Crow Wing Counties. Sites were planted as a randomized complete block design with single-tree plots.

In 2001 (after three growing seasons in the field) and 2003 tree heights were measured to the nearest centimeter using a height pole. In 2006 and 2008 tree heights were measured to the nearest decimeter using a Haglof© hypsometer. Tree diameters (outside bark) at breast height (1.3 meters) were measured using calipers to the nearest millimeter in 2006 and 2008. Additionally, stem straightness (stem form) and the incidence of gall rust (*Cronartium quercuum* or *Cronartium harnessii*) were both assessed in 2003 and 2008. Stem form was assessed on a scale of 1-6 using a key provided by the New Brunswick Tree Improvement Council (Fullarton, 2001):

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

In 2003, gall rust was assessed using a 3-point scale:

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

In 2010, a subsample of trees was assessed for presence of rust:

0 = No rust
1 = Gall rust observed on lateral branches only.
2 = gall rust observed on main stem only.
3 = gall rust observed on both the main stem and lateral branches
4 = no data available.

The severity of rust was also categorized in 2010:

0 = No rust observed
1 = Low severity (1 gall)
2 = Mediums severity (more than 1 but fewer than 4 galls)
3 = High severity (greater than 4 galls)

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

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

Also in 2010, cone serotiny was assessed on a subsample of trees using a 3-point scale:

1= Fewer than 1/3 of all cones on a tree were open
2= Between 1/3 and 2/3 of cones were open
3= More than 2/3 of cones were open cones

Cones assessed for serotiny were also assessed for stature (curled or straight).

All quantitative variables (height, diameter, volume) and the quasi-quantitative trait (stem straightness) were tested for normality and variance stability. Tree heights, diameter, and volume were in compliance with ANOVA assumptions and did not require further transformations. Quantitative variables were thus further analyzed with analysis of variance using Proc mixed in SAS with the model:

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

where Y is total tree height, diameter or volume, μ is the overall mean, S_j and F_k are the fixed 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 Restricted Maximum Likelihood Method (REML) using Proc mixed in SAS with the model:

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

where Y is total tree height, diameter or volume, μ is the overall mean, R_j is the random effect of replication (18 reps), F_k is the fixed effect of family (1 - 100), respectively and ε_l is the experimental error. Narrow-sense (h^2_i) tree heritabilities were calculated for all traits at each site using the equations:

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

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.

To measure ecological similarities, the ANOVA was run by grouping families according to their native floristic region. Because trees were full-sib, the floristic regions for each family were determined by the origin of their two parents, resulting in six ecological categories (Table 1). No reciprocal cross for "ns" was made. These assignments were made years after the crosses were made, so the number of families per cross type is not balanced.

Table 1. Key to the ecological classifications of progeny, assigned based on the original location of parent trees according to the Fire-dependent (FD) woodlands (MN DNR, 2003).

Maternal origin	**Paternal origin**	**Ecological class of progeny**
FDn	FDn	‘nn’
FDn	FDc	‘nc’
FDc	FDn	‘cn’
FDc	FDc	‘cc’
FDc	FDs	‘cs’
FDs	FDc	‘sc’
FDn	FDs	‘ns’

Results

Survival at the two sites was excellent (Table 2). Mortality since 2001 is attributed to gall rust (both sites) and pocket gophers (Crow Wing). By 2008 crown closure was nearly complete. Significant differences among families occurred for all variables except branch angle (Table 3). Genotype by environment interactions were significant for all variables except branch angle, cone stature and cone serotiny.

Table 2. Survival by site and year.

		Percent survival			
Site	**No. planted**	**2001**	**2003**	**2006**	**2008**
Crow Wing / MN DNR	1800	95%	92%	89%	85%
St Louis / IRR	2574	92%	91%	91%	90%

Narrow-sense heritabilities were smallest for tree heights and volume, and largest for cone serotiny (Table 4). Heritabilities were lower at St Louis than at Crow Wing for all traits except stem form (2008) which was similar at both sites (0.29 Crow Wing, 0.30 St Louis). Branch angle was lower than expected but was similar among trees and this test is not an indicator of true heritability because of bias in the data (see discussion). A subsample of rust presence and severity was taken at Crow Wing County alone where disease pressure was high but was not taken at St Louis County because the incidence of rust was low.

Table 3. P-values for analysis of variance.

Source	DF	Height	Diameter	Volume	Stem Form	Branch angle	Cone Stature	Cone serotiny
Site	1	< 0.001	< 0.001	< 0.001	< 0.001	0.107	<.0001	0.0263
Rep	17	< 0.001	< 0.001	< 0.001	< 0.001	0.4224	0.0451	0.6899
Family	142	< 0.001	< 0.001	< 0.001	< 0.001	<.0001	<.0001	<.0001
Site * Family	99	0.0138	< 0.001	< 0.001	0.001	0.0718	0.6679	0.191

Table 4. Narrow-sense heritabilities for all data from all years.

	Crow Wing / DNR	St Louis / IRR
Height 2008	0.14	0.02
Height 2006	0.12	0.03
Height 2003	0.10	0.07
Height 2001	0.16	0.09
Diameter 2008	0.17	0.05
Diameter 2003	0.11	0.04
Volume 2008	0.19	0.04
Volume 2003	0.08	0.04
Stem Form 2008	0.29	0.30
Stem Form 2003	0.30	0.26
Rust presence 2008	0.45	na
Rust severity 2008	0.65	na
Rust 2003	0.19	0.03
Branch Angle	0.22	0.38
Cone Stature	0.55	0.62
Cone Serotiny	0.70	0.67

Genetic correlations were calculated for each site separately. At the Crow Wing / DNR site, volume was significantly genetically correlated with stem form, and volume was similarly correlated with cone serotiny (Table 5). In addition, stem form was genetically correlated with rust presence. At St Louis Co. / IRR site, volume was significantly genetically correlated with stem form, cone serotiny and cone stature (Table 6).

Table 5. Genetic correlations: Crow Wing for 2010 data.

DF = 636		Stem Form	Rust presence	Cone Stature	Cone Serotiny
Volume	**R2**	0.12	0.00	0.06	0.08
	p-value	<.0001	0.93	0.13	0.04
Stem Form	**R2**	1	-0.09	0.01	0.01
	p-value		0.02	0.73	0.75
Rust presence	**R2**		1	-0.03	0.06
	p-value			0.40	0.12
Cone Stature	**R2**			1	-0.06
	p-value				0.14

Table 6. Genetic correlations: St Louis County / IRR site for 2010 data.

DF = 1121		Stem Form	Cone stature	Cone serotiny
Volume	**R2**	0.12	-0.07	0.07
	p-value	<.0001	0.02	0.02
Stem Form	**R2**	1	0.00	0.03
	p-value		0.97	0.28
Cone stature	**R2**		1	0.05
	p-value			0.13

Tree heights were compared among floristic region assignments in Figure 1. At St Louis County, tree height did not differ significantly by floristic region type. However, at Crow Wing County families that originated from central regions (cc, cn, nc) were all significantly larger than trees with parents from the northern floristic region (nn).

Tables 7 and 8 contain all data summarized by family for tree volume, serotiny, stature, and rust. Only the top 25% of families at each site is shown. A family was assigned to a category if more than 50% of trees in the family were classified in that category. Otherwise, if fewer than 50% of trees in a family were assigned to a category then it was classified as indeterminate. This artificial cut-off was applied to cone serotiny, cone stature, and susceptibility to gall rust.

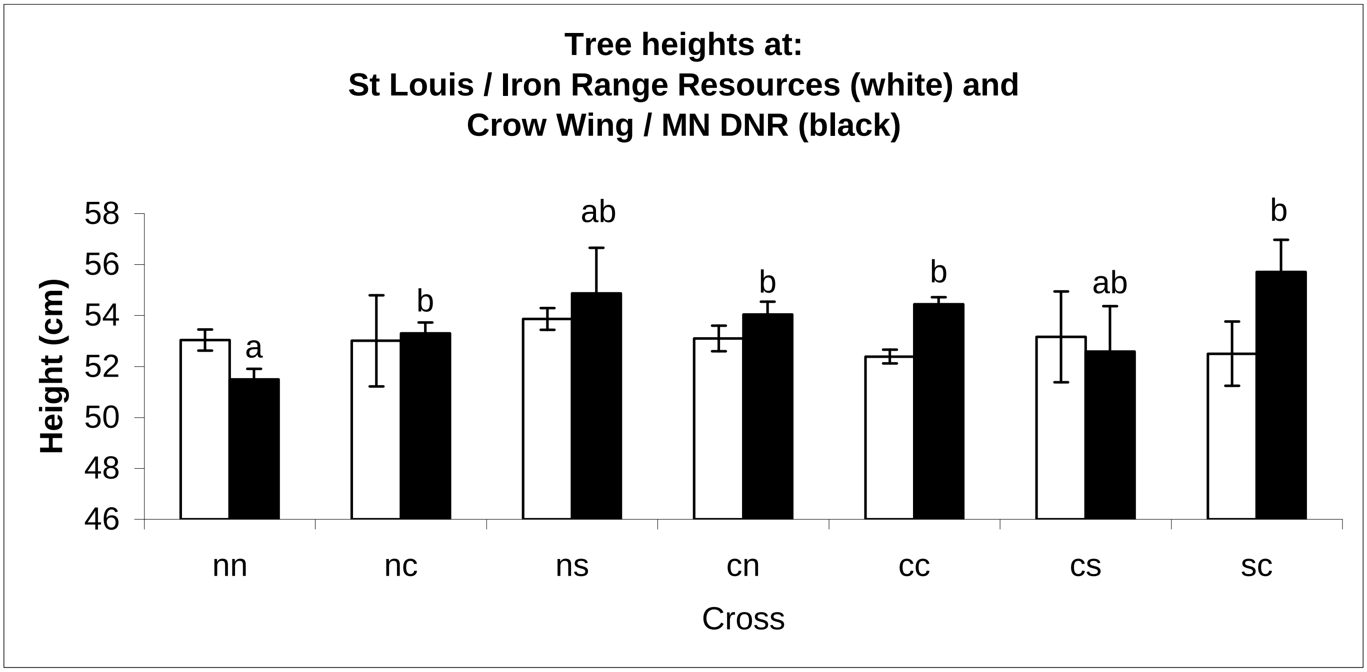


Figure 1. Tree heights at two second-generation jack pine sites. Letters above the bars indicate significant differences among cross types within each site. No significant differences among types was revealed at St Louis County site.

Discussion

Families differed significantly for all quantitative and qualitative variables. This is not surprising given the large sample size, good survival and relatively balanced dataset. Low heritabilities for height, diameter and volume at St Louis were attributed to the heterogenous nature of soil at that site. Site variability was highly visible during fence construction, when holes were dug for fence posts. Each hole varied, in a short distance, from the other in terms of water-holding capacity. One hole would fill with water with no water pooling in an adjacent hole. The site at St Louis County was maintained through careful mowing, so the high degree of phenotypic variation is probably due to soils and not competing vegetation, which was largely controlled.

The significant interaction of family by sites for growth traits indicates that families are not broadly adapted. This was verified by the unexpected genetic correlation between cone serotiny and volume growth. Trees with closed cones performed poorly at Crow Wing county, where that serotiny type is less common. In St Louis County, top families consisted of both serotiny types. Cone stature was not genetically correlated with growth, which was surprising since straight cones are more typically associated with north east Minnesota (Shoenike 1976) and curled cones are associated with central and western parts of the state. Tall trees were also straighter at Crow Wing County, thus selection on growth does not appear to have negative tradeoff with other desirable traits. Serotiny is known to vary with tree age, and eleven years of growth is still considered "juvenile" for jack pine with respect to serotiny (Gauthier et al 1993). Trees become more serotinous, that is they produce more closed cones, with age. In this dataset, trees with larger diameters did not necessarily possess more closed cones. In contrast, larger trees tended to have a greater percent of open cones (data not shown). However, ontogenetic effects, effects that vary with juvenility, are difficult to separate at this sub-mature state. A subsample of trees from each family should be maintained to enable a re-assessment of serotiny in the future, after trees have matured.

Cone traits did not discriminate perfectly with their origin (Table 7), and could not be divided into clear groups based on cone traits alone (results of this analysis are not shown here.) There are several reasons why cone traits don't perfectly resemble their predicted "ecotype." For one, the practice of matching seed origin to a planting site is relatively recent. Historically, jack pine seedlings (among other species) were planted without regard to seed origin. This was particularly common in the early 20th century before nurseries in North America were well established. It is possible that many mature stands are relics of former practices, and are composed largely of non-native seed sources. Secondly, sources that occur near the borders of floristic regions might not classify predictably. In some cases, GPS points that were assigned, based on latitude and longitude coordinates, landed a subject tree in a body of water or in other odd locations. Making predictions of offspring based on grandparents increases the variation. Even a trait like serotiny, that has high heritability, does not transmit perfectly from parent to offspring. The expression of this trait may vary slightly in different environments and may change in frequency from parent to offspring. Lastly, epigenetic effects may also play a role in the expression of plant traits. In this second-generation population, each unique family was crossed at a single site confounding measurements of the sites themselves on the expression of traits. It is possible that serotiny may be affected by the environment in which the tree resides. The drier environment in Crow Wing county could influence the appearance of serotiny at that site. In addition, the possibility of an epigenetic effect, where the environment in which the seed forms affects the resulting phenotype, cannot be ruled out but is confounded in this population.

Families selected for fast-growth should be deployed to sites from the same floristic region. In other words, orchards in central floristic regions should be composed of families with best volumes at Crow Wing County, and orchards in the northern regions should be composed of families that performed best at St Louis County. Cooperators may favor families with straight cones to increase seed production since this trait did not genetically correlate with other traits. Curled cones are less desirable than straight cones because seeds on the interior of the curvature are often mal-formed. Although non-serotinous cones are less desirable for seed procurement efforts, families with open-cone types performed best in the central region and should be favored. In another study, sources that originate from warmer and drier climates have higher radial growth than sources from more northerly latitudes (Savva et al 2007). In Minnesota, the north and central floristic regions are characterized by different serotiny and stature types (Schoenike 1976), with central sources possessing traits associated with warmer, more southerly climates. In northern regions, orchards should be composed of a combination of open and closed cones, favoring the latter for ease of seed procurement. A series of improved second-generation grafted orchards are planned for MTIC cooperators in the near future using these guidelines.

Table 7. Descriptive summary of categorical variables for the top 25% of families at the St Louis County / IRR site. Trees from the best families will be selected as ortets for future improved 2nd-generation orchards. Volumes were sorted in descending order so the largest family has rank = 1. ECS class is based on the 2003 MN DNR Fire-dependent floristic regions. The letters present the location of the maternal and paternal grandparents of each cross.

Family	Volume Rank SL	Cone Serotiny	Cone Stature	Suscept.to gall rust	ECS class
2107	1	closed	curled	#N/A	cn
2117	2	open	straight	#N/A	cc
2137	3	indeterm.	straight	#N/A	cn
2143	4	open	straight	#N/A	cc
2101	5	open	straight	mod	nc
2127	6	open	indeterm.	indeterm.	cc
2229	7	indeterm.	straight	#N/A	cn
2135	8	open	straight	mod	cc
2166	9	open	straight	mod	cc
2194	10	open	curled	#N/A	cn
2227	11	open	indeterm.	hi	nn
2242	12	indeterm.	straight	mod	cc
2215	13	open	straight	indeterm.	cc
2210	14	closed	curled	mod	nn
2221	15	open	straight	#N/A	nn
2193	16	open	straight	#N/A	nn
2195	17	closed	straight	#N/A	cc
2144	18	open	curled	mod	nn
2156	19	closed	straight	#N/A	nn
2201	20	indeterm.	curled	#N/A	nc
2211	21	open	curled	mod	cn
2140	22	open	curled	indeterm.	nn
2167	23	open	straight	mod	cc
2182	24	open	straight	mod	cc
2248	25	open	curled	#N/A	No data
2228	26	open	curled	#N/A	nn
2158	27	open	curled	mod	nn
2251	28	closed	indeterm.	low	cc
2118	29	indeterm.	straight	mod	cc
2102	30	open	straight	low	cc
2103	31	open	straight	mod	cc
2196	32	open	straight	hi	nn
2105	33	indeterm.	curled	indeterm.	cc
2230	34	open	curled	indeterm.	cc
2120	35	mixed	straight	mod	nc

Table 8. Descriptive summary of categorical variables for the top 25% of families at the Crow Wing County / MN DNR site. Trees from the best families will be selected as ortets for future improved 2nd-generation orchards. Volumes were sorted in descending order so the largest family has rank = 1. ECS class is based on the 2003 MN DNR Fire-dependent floristic regions. The letters present the location of the maternal and paternal grandparents of each cross.

Family	Volume Rank CW	Cone Serotiny	Cone Stature	Suscept.to gall rust	ECS class
2209	1	closed	straight	indeterm.	sc
2095	2	open	straight	hi	cc
2169	3	open	straight	mod	cc
2183	4	open	straight	low	cc
2182	5	open	straight	mod	cc
2103	6	open	straight	mod	cc
2160	7	open	straight	mod	cn
2134	8	open	curled	low	cc
2168	9	indeterm.	straight	mod	cc
2174	10	indeterm.	curled	mod	cc
2202	11	open	curled	mod	cn
2111	12	open	straight	mod	cn
2098	13	open	curled	mod	nn
2096	14	closed	straight	mod	cn
2094	15	open	curled	low	cc
2126	16	indeterm.	straight	low	cc
2167	17	open	straight	mod	cc
2120	18	mixed	straight	mod	nc
2127	19	open	indeterm.	indeterm.	cc
2208	20	open	straight	indeterm.	cc
2161	21	indeterm.	curled	hi	nc
2119	22	open	indeterm.	hi	cn
2093	23	open	straight	low	cc
2192	24	open	curled	hi	nc
2124	25	open	indeterm.	low	nc

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D. Five-year heights from 2nd generation white spruce population

By: C. Pike

This section is revised from a paper that appeared in 2007 MTIC Annual Report

Abstract

Controlled crosses, produced using a positive assortative mating design, were made at a breeding arboretum in Willow River, Minnesota between 1998 and 2002. Seed was germinated and planted in 2003 and 2005. Five-year survival ranged widely among sites due to high levels of environmental heterogeneity. Genotype by environment interaction was significant, and high levels of within-family variation were present. Heritabilities for tree height were lower than anticipated, but are expected to increase with age.

Introduction

A tree improvement program was initiated for white spruce in the lake states in the late 1960s. UPM-Blandin's 'L' seedling-seed orchard began as an open-pollinated progeny test from trees selected for growth and form traits from northern Minnesota. Selections from southeastern Ontario were combined with selections from the seedling-seed orchard for the development of the tree improvement program, and most orchards in the MTIC contain material from both provenances. A first-generation open-pollinated progeny test was established by members of the MTIC in 1986 and continues to be measured and utilized for data collection. In addition, over 250 genotypes were grafted into the A- and B- block breeding arboretums at the General Andrews Nursery in Willow River to provide easy access to parent material for the production of a second-generation population. This report summarizes five-year findings from all second-generation populations that were established in 2003 and 2005.

Methods

All controlled crosses were made at the MN DNR's General Andrews Nursery in Willow River, Minnesota at an established white spruce arboretum produced from grafted stock. The arboretum is split into two areas at the nursery, called "A" and "B" blocks. Controlled crosses were made in the years 1998, 2000, and 2002. Ten-year tree heights were averaged for each family from a separate white spruce progeny test using data collected from five sites. A positive assortative mating design (PAM) was used to determine mating pairs, in which the top-ranked family (rank 1, as determined from the progeny test) was mated with the second-largest family (rank 2), rank 3 was mated with rank 4, until all families were utilized. Maternity or paternity for each controlled cross was determined on flower availability. If male or female "inflorescence" (herein referred to as "flowers") were not present then that family was not crossed. Some adjustments in the PAM were made to accommodate variations in flower patterns. From breeding work in 1998 and 2000, 56 full-sib families were produced. Seed from these crosses was germinated in fall 2002. In spring 2002, 115 crosses were created at the breeding arboretum in Willow River, and germinated in fall 2004 at the (now former) Potlatch greenhouse in Cloquet. All seedlings were grown in Ray Leach "Cone-tainer" RLC4 Pine Cell (UV Stabilized) tubes. In 2003, 49 families from the 1998/2000 crosses were planted into each of two sites (Itasca County and MN DNR-E), and 56 families were planted into St Louis County's orchard. Each site contained 16 replications, and trees were planted at 10 x 10 ft spacing. One border row was planted around each site containing woods run material provided by the land manager. In 2005, 115 families from the 2002 crosses, plus an additional 10 seedlings from the 1998/2000 crosses were planted at each of three sites. In fall 2007, after five growing seasons, tree heights were measured using a height pole to the nearest centimeter at the sites planted in 2003. In fall 2009, tree heights were measured at the sites planted in 2005. Data collected after five growing seasons from all sites is reported here.

Statistics

Tree heights from each site were checked for deviations from assumptions of normality and homogeneity of variances. All sites were nearly normally distributed, with skewness varying from mild (Blandin) to moderate (Lake County). At this time, no data transformations were performed, but should be considered in a final analysis, especially where differences were not detected. Analysis of variance was run on sites combined using general linear models (SAS, 2003) with sites, reps, and site * family as fixed variables. The analysis was repeated on each site separately with reps as random variables and family as fixed using a mixed-models ANOVA (SAS, 2003). Least-squared means of five-year tree heights were estimated for each family and families were ranked in descending order. Variance components were found using a Restricted Maximum Likelihood Method (REML) method which uses a mixed models approach (SAS, 2003) with the model:

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

where Y is total tree height, μ is the overall mean, R_j is the random effect of replication (8-16 reps), F_k is the random effect of family (49-111), respectively and ε_l is the experimental error. Narrow-sense (h^2_i) tree heritabilities were calculated for all traits at each site using the equation (Falconer and MacKay 1996):

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

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.

Results

Survival varied widely among sites (Table 1). Itasca County's posted the best survival among plantings established in 2003. Among sites established in 2005, survival was highest at Blandin's site.

Table 1. Survival after five growing seasons by site.

Manager	Year Planted	Reps	Families	Trees planted	Trees alive	Survival
MN DNR	2003	16	49	784	400	51.0%
St Louis Co.	2003	16	56	896	389	43.4%
Itasca Co.	2003	16	49	784	693	88.4%
MN DNR	2005	8	110	877	389	44.4%
Lake Co.	2005	9	100	900	824	91.6%
UPM-Blandin	2005	15	111	1645	1535	93.3%

Site, family, and site * family interactions were significant with 95% confidence (Table 2). The significant site by family interaction forced a separation of ranks by site. The overall ANOVA model was not significant at the 2003 DNR site or Lake County, indicating a lack of model fit (Table 3). At the other four sites, family differences were detectable with over 95% confidence (Table 4).

Table 2. Significance of site, family and site * family interaction from analysis of variance using general linear models in SAS(2003).

Source	DF	Pr > F
Site	5	<.0001
Fam	158	<.0001
Site*Fam	310	0.0057

Table 3. Significance of analysis of variance model by site.

Site	DF	F Value	Pr > F
DNR - 03	49	1.01	0.4677
St Louis - 03	55	1.62	0.0057
Itasca - 03	49	2.38	<.0001
DNR - 05	110	0.95	0.0076
Blandin - 05	111	1.62	<.0001
Lake - 05	100	1.2	0.3224

Table 4. Significance of family differences by site using mixed models with rep as a random variable, and family as fixed in a mixed model (SAS, 2003).

Site	Family
DNR - 03	0.4552
St Louis - 03	0.005
Itasca - 03	<.0001
DNR - 05	0.007
Blandin - 05	0.0001
Lake - 05	0.3233

Tree heights were tallest at Blandin's property followed by MN DNR's 2005, Itasca County, DNR 2003, Lake County, and St Louis County (Table 5 and Figure 1). Sites planted in different years have a different compliment of families (Table 6). Sites planted in 2003 and 2005 share 10 families in common to facilitate comparisons among all sites.

Heritabilities ranged from 0 (at DNR-03) to 0.20 (at DNR-05). At sites with the best survival (Blandin and Itasca County), estimated heritabilities were 0.12 and 0.18 , respectfully (Table 5).

Figure 1. Average tree heights after five growing seasons at each site.

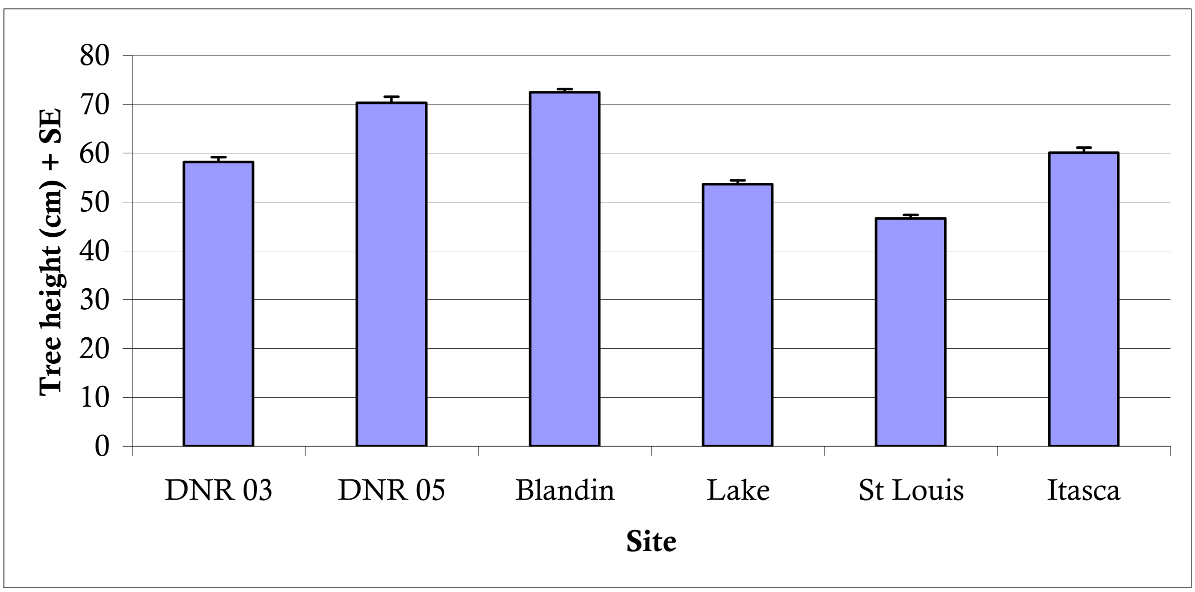

Table 5. Narrow sense heritabilities for five-year tree height by site.

	Narrow-sense h2
DNR - 03	0.00
Itasca - 03	0.18
St Louis - 03	0.17
DNR - 05	0.21
Blandin -05	0.12
Lake - 05	0.02

Discussion

Most of these plantings experienced high levels of environmental heterogeneity, leading to lower than expected heritabilities and a weakened ability to detect family differences. Mortality at St Louis County was attributed to droughty soil and heavy grass competition. At the MN DNR sites, competing vegetation along with patchy low spots contributed to mortality. Following the 2003 planting, equipment used to apply herbicide unintentionally damaged seedlings. At Itasca County, pockets of mortality were generally located where thistle plants were dense, but overall survival was very good.

Ranks were unstable across sites (Table 6), likely due to environmental effects. Less than 10% of phenotypic variation was attributed to family effects, as reflected by lower than expected heritabilities. Heritabilities are likely to increase in future datasets, as trees become more established (Niendstaedt and Riemenschneider 1985). This was observed in the first-generation progeny test where g x e interactions were not significant for superior trees (Klevorn 1995). The family means were not standardized for block differences in this analysis. In future analyses, standardizing family means for block effects may enhance genetic differences among families.

Height growth in "superior" white spruce families has exceeded un-selected families by 30% in Minnesota (Nienstaedt 1981) and more recently in trials comparing woods run and orchard sources where volumes exceeded 30% (Pike et al., 2002). Ontario sources grow faster than local sources, especially compared to those from higher latitudes (Radsliff et al 1983), even in the east (Tebbetts 1981). Heterosis between Ontario and Minnesota sources has not been found (Wang 2000), so selections from the second-generation population will likely consist of a combination of Ontario and Minnesota sources, and crosses between them. Additional analyses on future datasets (10-year growth) will compare the growth of Minnesota x Minnesota crosses with Ontario x Ontario crosses and their hybrids. If family x site interactions persist, then seed zones for improved material would become necessary.

Continued vegetation management is necessary to maintain vigor and promote growth. In future datasets, families will be ranked using standardized means, to facilitate comparisons among sites and years. Sites will be measured after ten, 15, and 20 years of growth. "Superior" families will be selected from these sites after year ten to produce advanced generation orchards. Trees at these sites will be used as ortets for the production of improved second-generation orchards in the future.

Table 6. Family ranks within each site. Mid-parent ranks were generated from first-generation progeny test using 15-year volumes. Trees with largest volumes are represented by lower ranks (largest family with rank 1).

Mid-parent rank	DNR-03	Itasca-03	St Louis-03	DNR-05	Blandin-05	Lake-05
1.5	.	.	.	33	27	5
3.5	.	.	.	76	15	58
7.5	.	.	44	.	.	.
8.5	.	.	.	18	79	6
10.5	.	.	.	36	100	7
12.5	.	.	.	37	36	41
13	7	6	13	.	.	.
14.5	.	.	.	6	12	30
16.5	.	.	.	99	14	77
18.5	.	.	.	69	39	.
20	44	48	.	.	.	.
20.5	.	.	.	106	7	42
23	.	.	.	60	63	84
24.5	.	.	.	53	87	91
24.5	17	14	17	.	.	.
26	.	.	.	62	57	88
28.5	.	.	.	84	77	82
29	.	3	50	.	.	.
30.5	.	.	.	.	64	.
32	23	37	26	.	.	.
34.5	.	.	.	20	31	90
36.5	.	.	.	27	47	39
38.5	.	.	.	108	49	40
40.5	26	28	53	8	32	9
41.5	.	.	.	79	26	.
41.5	38	36	32	.	.	.
45	.	.	.	17	94	51
47.5	.	.	.	43	79	85
50.5	.	.	.	49	3	33
54	.	.	.	59	82	.

58.5	.	.	.	78	97	86
60.5	.	.	.	10	25	53
61	39	35	37	.	.	.
65.5	.	.	.	94	70	28
67.5	.	.	.	64	111	59
69.5	.	.	.	61	108	66
71.5	13	15	21	.	.	.
73	.	.	52	.	.	.
73.5	.	.	.	89	53	16
74.5	6	8	29	.	.	.
74.5	34	5	36	.	.	.
77	.	.	.	41	110	100
78.5	.	.	.	109	72	96
84	24	32	38	.	.	.
84.5	.	.	.	101	46	62
88.5	.	.	.	22	52	52
89.5	2	25	2	.	.	.
93	.	.	.	2	22	25
95	.	.	.	35	38	1
98	.	.	40	.	.	.
98.5	.	.	.	52	4	43
99.5	42	46	11	46	95	91
100	.	.	.	48	83	20
101	.	.	47	.	.	.
103.5	.	.	.	1	54	.
103.5	16	11	41	.	.	.
105	11	2	3	9	72	94
106.5	.	.	.	21	104	99
107.5	43	34	54	.	.	.
109	14	13	6	.	.	.
112.5	.	.	.	56	11	10
114.5	.	.	.	53	98	.
117.5	.	.	.	38	59	73
120.5	.	.	.	13	23	66
123	.	.	.	73	40	.

123.5	.	.	.	11	90	63
126.5	.	.	.	84	58	69
129	.	.	.	5	91	29
129	.	.	.	40	69	.
131.5	.	.	.	100	62	45
132	20	27	16	.	.	.
132	45	9	12	.	.	.
134.5	.	.	.	95	74	44
135	12	30	20	.	.	.
136.5	.	.	.	55	105	48
136.5	27	41	22	42	16	22
136.5	35	43	23	.	.	.
137.5	32	4	31	.	.	.
140.5	36	12	28	.	.	.
141.5	25	49	51	.	.	.
142	.	.	.	71	21	68
142	40	7	46	.	.	.
143.5	19	21	48	.	.	.
146.5	.	.	.	26	101	26
149.5	.	.	.	72	84	.
150.5	.	.	.	88	106	93
151	5	24	18	23	34	69
154.5	.	.	.	29	48	57
156	49	47	55	87	70	32
156	1	19	1	.	.	.
158	31	42	39	.	.	.
159	.	.	.	83	37	75
161.5	.	.	.	65	56	63
163.5	.	.	.	7	43	24
165.5	.	.	.	77	17	75
166.5	.	.	.	4	81	47
168	18	16	24	.	.	.
169.5	.	.	.	98	50	78
172.5	.	.	15	.	.	.
173	.	.	.	92	33	59

177.5	.	.	.	33	76	2
179.5	.	.	.	56	35	23
181.5	.	.	.	89	6	.
183.5	.	.	.	45	93	46
183.5	30	20	34	86	17	56
183.5	.	.	33	.	.	.
187	3	.	4	.	.	.
188.5	.	.	.	23	2	11
189.5	.	.	.	70	74	33
190	29	1	5	63	66	17
191.5	41	23	49	.	.	.
193.5	.	.	.	79	84	88
195	.	.	.	15	101	71
195	15	26	45	.	.	.
195.5	47	29	35	.	.	.
197	37	10	8	.	.	.
198.5	.	.	.	75	10	98
201.5	.	.	.	95	1	3
202	22	40	30	.	.	.
204.5	.	.	.	66	59	49
207.5	.	.	.	105	20	19
209	.	.	7	.	.	.
210	.	.	.	66	41	82
211.5	.	.	.	104	30	12
214.5	.	.	.	110	51	21
217	46	31	19	.	.	.
218	.	.	.	103	19	53
220	.	.	.	50	77	50
221.5	.	.	.	97	68	73
222	8	33	25	43	99	26
225.5	.	.	.	30	28	36
227.5	28	45	9	.	.	.
228	4	22	10	.	.	.
228.5	.	.	.	13	87	4
231.5	.	.	.	12	109	97

233	33	44	43	.	.	.
234	.	.	.	51	67	65
237	.	.	.	39	44	8
239	.	.	.	107	9	38
244.5	.	.	.	81	107	35
247.5	.	.	.	31	54	13
248.5	.	.	.	91	29	.
253	.	.	.	102	45	30
254.5	.	.	.	47	23	53
255	21	39	27	.	.	.
255	9	17	14	.	.	.
256.5	10	18	.	.	.	.
261	48	38	42	.	.	.
262	.	.	.	82	103	80
263	.	.	.	28	13	14
265.5	.	.	.	92	65	36
268	.	.	.	3	59	59
269	.	.	.	19	8	79
272.5	.	.	.	32	91	18
274.5	.	.	.	16	96	95
276.5	.	.	.	58	5	81
282.5	.	.	.	66	42	15
284	.	.	.	23	84	71
291	.	.	.	74	89	87
Total	49	49	55	110	111	100

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E. Ten-year survival and heights on 1999 progeny test (eastern white pine)

By: C. Pike

Abstract

Eighteen open-pollinated progeny were planted in 1999 at four sites in a triple-repeated latin square design with a single border row. Data from two sites are analyzed below. Mortality and signs of blister rust were recorded after ten field seasons and tree heights were measured. Rates of survival differed significantly among families at Superior but not at ORSO, but no pairwise differences between families were significant at either site. Families did not differ significantly with respect to tree height but the site * family interaction was significant. Families that are selected for significance to blister rust may require additional progeny testing to insure that growth rates are not reduced in future improved populations.

Introduction

This project was initiated by Dr Paul Zambino, Plant Pathologist with the USDA Forest Service at the San Bernadino National Forest in California. These white pine plantings were established during his tenure at the Northern Research Station in Rhinelander, WI. The goal of these plantings was to compare resistance to white pine blister rust disease in the field with resistance measured through controlled inoculations in the laboratory. The field sites relied on naturally-occurring *Ribes* sp., the alternate host for blister rust disease, and no additional plants were added to enhance disease incidence.

Methods

A total of 18 open-pollinated seed sources of eastern white pine were tested. Sixteen families were selected because they demonstrated some level of resistance in prior inoculation tests conducted at USDA Forest Service facility in Rhinelander, WI (P. Zambino, personal communication). Two bulked sources were used as controls. One came from the Oconto River Seed Orchard in White Lake Wisconsin, and the other from Menominee, WI (Table 1). Seed was stratified in January 1994, germinated in early 1998, and planted in May, 1999. A germination test on each seedlot revealed rates of 0.69-0.99(69 – 99 %). The seedlings were grown into SC-10 Ray Leach Cone-tainers (Stuewe and Sons, Inc.).

Four sites were cleared and prepared for planting, one each in Oconto River Seed Orchard in east-central Wisconsin, and in Minnesota at St Louis County's orchard complex, the Superior National Forest, and Itasca County. The site at Itasca County was abandoned the year after planting due to extensive deer browse. The other sites remain in good condition.

Seedlings were deployed in a triple-repeated latin-square design. Each latin square contained one seedlot for each row and column, for a total of 972 test-seedlings per site (54 trees per seedlot per site). At Superior NF and St Louis County, trees were planted four feet apart on all sides, with a border row surrounding the outside of the entire planting (no border trees separate adjacent latin-square blocks). At ORSO trees were planted six feet apart on all sides. All trees were hand-planted in May 1999 with shovels. Mortality was assessed after 3, 5, 8, and 10 growing seasons. Tree heights were measured after 10 growing seasons. Rust was recorded during mortality surveys. The ten year data from St Louis County has not been collected yet.

Statistics

Survival was compared among seed sources at the Superior and ORSO sites using general non-linear function for mixed models (SAS, 2003). All trees that were dead in 2009 were noted on a binary scale (alive, dead) with rep as a random effect and family as fixed. A multiple comparison procedure was conducted using Tukey's adjusted means on survival. Tree heights among sites, reps, and families were compared using a mixed model ANOVA (SAS, 2003) with site and reps as random variables and family as fixed.

Table 1. Families included in the white pine progeny test. H109 and H111 were included as susceptible controls. P327 was included as a resistant control. The "year" represents the year seed was collected.

Parent	Seedlot	Year
CH107	4583A	1986
H109	5225A	1990
H 111	5226A	NA
MI 12	7532	1979
O 122	7752	1979
ON 538	3479A	1982
P 18	5338A	1992
P 30	5339A	1992
P 312	5340A	1992
P 327	5231A	1990
P 343	5232A	1990
SE 22	5188A	1990
U 13	5233A	1990
WI 342	from 96	1996
WI 352	5240A	1990
ON469	6499	NA
ORSO92-bulk	A0587-4	1992
Menominee-bulk	H221-PW	1995

Results

Survival did not differ significantly among families at ORSO, but differed among families at Superior (Table 2). Tukey's adjusted means did not reveal significant differences between any pair-wise comparisons at the Superior site, so the significant effect of family at Superior may be artificial. Alternatively, the Tukey's test may be too conservative to detect differences. Survival of the positive and negative controls is not dissimilar to each other or to other families whose resistance status is unknown (Figure 1).

Table 2. Results of logistic regression for survival at ORSO and Superior.

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Family at ORSO	17	952	0.8	0.6961
Family at Superior	17	952	1.88	0.0166

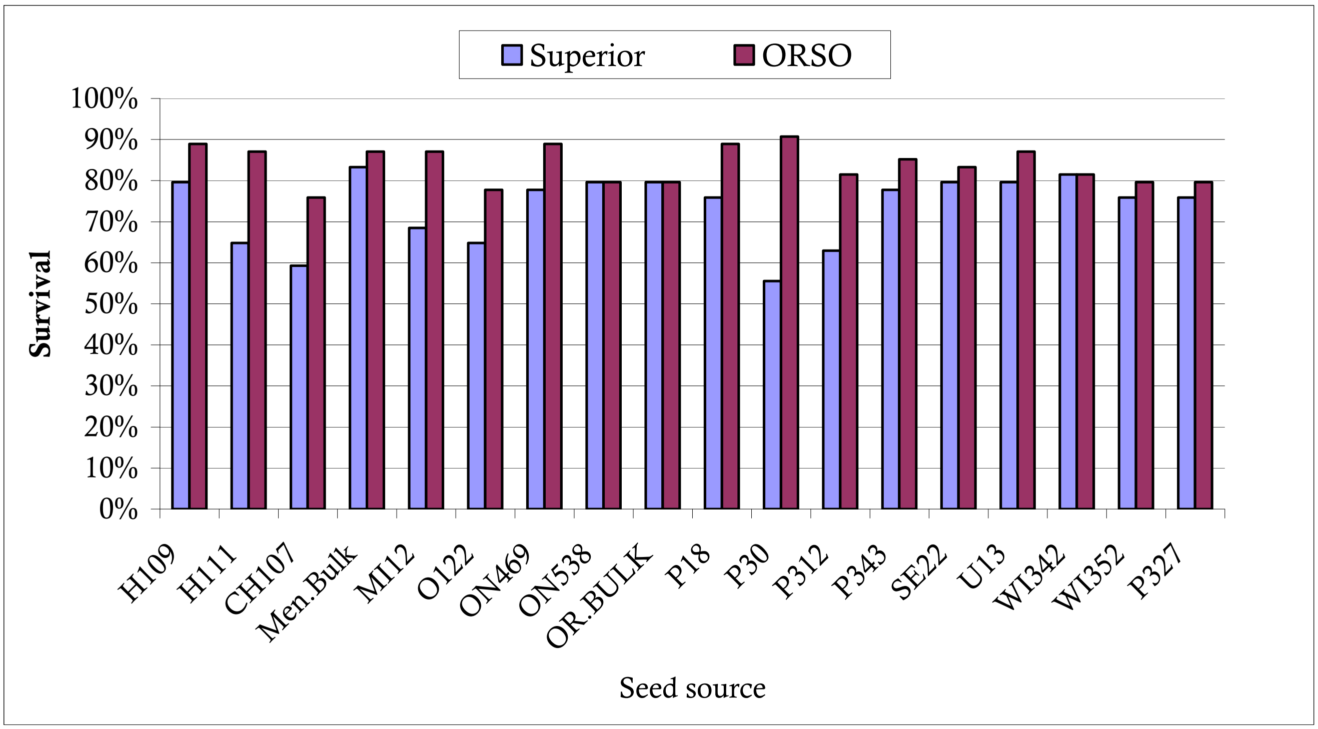

Figure 1. Survival for each seed source at each of two locations. No significant differences were found for any pair-wise comparisons at either site. H109 and H111 are susceptible controls. P327 is a resistant control.

For the full model (Table 3), no significant differences were revealed among families for tree height. Differences among sites and family * site interactions were significant. Table 4 shows significance for family at each site. No differences among families were detectable at $p<0.05$ at either site. Ranks, assigned for each site, are shown in Table 5. Presence of significant g x e interaction is visible for nearly all genotypes, notably P343 and P312.

Table 3. ANOVA table generated from mixed models procedure for tree heights.

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Site	1	1489	14.62	0.0001
Family	17	1489	0.88	0.6007
Site*family	17	1489	1.68	0.0401

Table 4. Significance of family effects for tree heights after 10 growing seasons.

Type 3 Tests of Fixed Effects		
Effect	F Value	Pr > F
Family at ORSO	0.94	0.5315
Family at Superior	1.58	0.0636

Table 5. Mean tree height for each family (in centimeters) at Superior and ORSO.

Superior families	Means at Superior	SE, Superior	Rank at Superior	Means at ORSO	SE, Orso	Rank at ORSO
ORSO92, bulk	280.3	16.4	1	308.0	14.7	15
P343	266.3	16.5	2	298.4	14.5	18
ON538	264.6	16.4	3	321.0	14.7	4
O122	260.9	17.2	4	312.3	14.8	10
Menominee, bulk	257.3	16.2	5	308.5	14.4	13
H111	257.0	17.1	6	300.0	14.4	17
P18	254.7	16.5	7	302.9	14.3	16
SE22	254.1	16.4	8	313.1	14.6	9
P30	252.7	17.8	9	319.2	14.3	6
P327	249.1	16.5	10	321.0	14.7	3
ON469	246.8	16.5	11	309.3	14.3	11
U13	246.4	16.4	12	332.3	14.4	2
H109	244.8	16.4	13	321.0	14.3	5
WI352	241.8	16.5	14	308.8	14.7	12
P312	235.5	17.3	15	332.5	14.6	1
CH107	230.8	17.5	16	314.6	14.9	8
WI342	228.2	16.3	17	308.4	14.6	14
MI12	227.9	16.9	18	315.5	14.4	7

Discussion

Survival did not differ significantly among seed sources or sites. This was not surprising due to the lack of rust. Rust incidence at the third site in St Louis was low and is not included in this dataset. (Tree heights and survival will be measured in spring 2011.) Families included in this progeny test were selected for potential rust survival, not for growth, so the lack of differentiation for tree height was not unexpected. Baseline tree height data was obtained, and should be stored as a reference for performance. Significant gxe interaction indicates that families don't perform equally at the two locations, and seed zones may need to be delineated in the future for rust-resistant material. Ten-year heights are similar to previous studies where 10-year heights ranged from 4 to 7 meters (Kuser, 1992), and averaged 200 cm (Mullin, 1978). Ongoing greenhouse screenings at Oconto River seed orchard, coupled with a new disease garden to test field resistance are planned. In addition, a progeny test is planned to compare tree heights among a variety of families from the MTIC program, including families selected for potential rust resistance and families selected for growth traits. This progeny test is slated for 2013.

F. Progress report on Pike's graduate research

Evaluation of phenotypic and physiologic characteristics of genetically improved white spruce

C. Pike

Progress was made on several fronts in 2010 towards completion of a PhD in the Natural Resource Science and Management major, with an emphasis in ecology and genetics of forest trees. In spring, oral and written candidacy exams were successfully completed. Progress on various projects is described below, and has three parts. In *Part I* data on a variety of traits are being collected from 25-year old trees at the MTIC white spruce progeny test. In *Part II*, root:shoot ratios of containerized seedlings are being measured over time. An experimental warming study is ongoing for *Part III*, in which seedlings are subjected to simulated mid-winter thaws.

Part I. Data collection from white spruce progeny test

Dendrometer bands, aka dendro-bands, were placed on 24 trees at each of two sites, Lake County progeny test and DNR-N progeny test, in fall 2009. Beginning in early spring 2010, tree diameters were recorded weekly, with the invaluable assistance of Justin Mayne, Lake County Forester based in Finland. Pike and Warren collected weekly readings at the DNR 'N' progeny test. Growth commenced in early May and was completed by late September. This data will be analyzed in winter 2010.

In addition to the seasonal growth, 600 increment cores (one per tree, approximately 10 trees from each of 30 families at two sites) were collected starting in 2008 and ending in fall 2010. Cores were mounted and are being scanned and measured using C-Dendro software at the Cloquet Forestry Center. This data will be used to compare the response of families to local climate events. Wood density was assessed volumetrically on approximately 300 additional increment cores that were collected in 2008.

Part II. Root:shoot ratios in improved and unimproved sources of white spruce

This study was installed in May 2008, with the last sampling expected in fall 2013. In fall 2009 and 2010, 60 trees were destructively sampled, cleaned, dried, and weighed. The goal is to compare the allocation of above and below ground biomass within and among different seed sources of white spruce.

Part III. Effects of cumulative winter warming on phenology and growth of white spruce

This study was installed in May 2008, and will be completed in spring 2011. The first warming treatment was applied during winter 2010. Phenological traits were measured in spring and early summer of 2010. The study will be repeated in winter 2011 with the final phenological measurements in spring and early summer 2011. Phenological traits include time of budbreak, bud elongation, and cessation of bud growth. In fall 2009, before the warming treatment was applied, tree heights and diameters were measured. These measurements were re-taken in fall 2010 after the warming treatments were applied. The variation in responses will be compared among treatments and among seed sources, (five improved sources and two natural, un-selected sources). Two plots of 56 trees were subjected to each of the treatments listed below in winter 2010. The experiment will be repeated in 2011 with some alterations.

Treatment structure for warming experiment in winter 2010:

1. Control, no warming, no snow removed.
2. Snow removed and trees warmed for four days in February
3. Snow removed in February but trees not warmed. (Control for effects of snow removal in February)
4. Snow removed and trees warmed for four days in March
5. Snow removed in March but trees not warmed. (Control for effects of snow removal in March)
6. Snow removed and trees warmed for four days in April
7. Snow removed in April and trees not warmed. (Control for effects of snow removal in April)
8. Snow removed and trees warmed for four days each in February and March (Effects of sequential warming)
9. Snow removed in February and March and trees not warmed. (Control for effects of sequential warming)

Treatment structure for warming experiment in winter 2011:

1. Control, no warming, no snow removed.
2. Snow removed and trees warmed for six days in February
3. Snow removed in February but trees not warmed. (Control for effects of snow removal in February)
4. Snow removed and trees warmed for six days in March
5. Snow removed in March but trees not warmed. (Control for effects of snow removal in March)
6. Snow removed and trees warmed for six days each in February and March (Effects of sequential warming)
7. Snow removed in February and March and trees not warmed. (Control for effects of sequential warming)

Results update

Survival at both seedling trials is excellent, and no seedlings were lost as a result of any treatment. In Part 1, wood density was not significantly negatively correlated with growth, so families with fast growth were not distinguished as having lower wood density. This implies that trees with fast-growth can be selected without compromising wood density. Trees with low wood density are more prone to damage from wind or ice storms, factors that are expected to increase in a warming climate.

Dendrometer readings from 2010 suggest that trees that exhibit fast growth do so through an accelerated period of growth and possibly through an extended period of growth into the fall. These findings will be analyzed in winter 2010-2011 and new bands placed in winter 2011 to monitor growth weekly during the growing season in 2011 at two locations.

The warming experiment will be repeated in winter 2010-2011 and completed by summer 2011.

In Part 2 (biomass study), no significant differences were found for tree heights between selected and natural sources after the first growing season. A discriminant analysis revealed that improved sources possessed larger root systems than natural sources. Sources are likely to become more different, with respect to tree height, in future datasets. Sixty trees from the biomass study were sampled in fall 2010, and will be processed and analyzed in winter 2011. The biomass study will continue beyond the completion of Pike's dissertation.

In Part 3 (warming experiment), the first warming treatment was applied successfully in winter 2010. Trees that were warmed three times (a total of 12 days) did not experience an obvious acceleration in the timing of budbreak, but exhibited a reduction in height growth relative to un-warmed controls. Statistics on this dataset will be completed in 2011. Trees from improved sources also exhibited less variation with respect to budbreak and budset times than natural sources, but data analysis to verify significance of these findings is not completed.

Minnesota Tree Improvement Cooperative

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