PROCEEDINGS OF THE TWENTY-EIGHTH MEETING

OF THE

CANADIAN TREE IMPROVEMENT ASSOCIATION

PART 1 Minutes and Members' Reports
PART 2 Symposium

Integrating Tree Improvement with Sustainable Forest Management Practice

Integrating Tree Improvement with Sustainable Forest Management Practice

2002

CONFERENCE

L'intégration de l'amélioration des arbres à l'aménagement durables des forêts

COMPTES RENDUS DU VINGT-HUITIÈME CONGRÈS

DE

L'ASSOCIATION CANADIENNE POUR

L'AMÉLIORATION DES ARBRES

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2e PARTIE Colloque

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PROCEEDINGS

OF THE

TWENTY-EIGHTH MEETING

OF THE

CANADIAN TREE IMPROVEMENT ASSOCIATION

PART 1

Minutes and members' reports

Edmonton, Alberta
July 22-25, 2002

Editor
J.D. Simpson

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COMPTES RENDUS

DU

VINGT-HIUTIÈME CONGRÈS

DE

L' ASSOCIATION CANADIENNE POUR L' AMÉLIORATION DES ARBRES

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PROCEEDINGS OF THE TWENTY-EIGHTH MEETING OF THE CANADIAN TREE IMPROVEMENT ASSOCIATION

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BUSINESS MEETING MINUTES

CTIA/ACAA 28th Business Meeting Minutes

Bruce Dancik chaired the 28th Business Meeting of the CTIA/ACAA held at the University of Alberta, Edmonton, Alberta on Tuesday July 23, 2002. Fifteen members were present.

322 Minutes of the 27th Meeting
(as printed in the proceedings from the 27th meeting, Part I)

Motion: That the minutes of the 27th Business Meeting be approved as published.
Moved by: Jerry Klein
Seconded by: Michael Stoehr
Carried.

321 Membership

321.1 Honorary Membership

No nominations received.

321.2 Active Membership

The names of nominees were presented as follows:

Tim Gylander	Weyerhaeuser Canada Ltd. Drayton Valley, AB
Dave Kolotelo	BC Ministry of Forests Surrey, BC
Gwen McGimpsey	Manitoba Forestry Branch Winnipeg, MB
Florence Niemi	Daishowa-Marubeni International Ltd. Peace River, AB
Greg O'Neill	BC Ministry of Forests Vernon, BC
Yuhui Weng	Forest Genetics Ontario Sault Ste. Marie, ON

Motion: That the nominated Active Members be duly elected.
Moved by: Kathy Tosh
Seconded by: Jean Beaulieu
Carried.

321.3 Corresponding Membership

The following person was nominated:

Geoffrey Gooding	Geographic Dynamics Corp. Edmonton, AB

Motion: That the nominated Corresponding Member be duly elected.
Moved by: Sally John
Seconded by: Narinder Dhir
Carried.

322 Chair's Report

The 28th meeting of the association was held as part of a joint meeting of the CTIA, the Poplar Council of Canada, and the Western Forest Genetics Association. Planning for this conference, "Integrating Tree Improvement with Sustainable Forest Management Practice", was done with the assistance of members from all three associations. Organizing the conference required the extra efforts of many people and the support of their employers in ensuring its success. The following individuals and their employers generously provided time and extra effort to ensure that the conference was a success:

Leonard Barnhardt, Alberta Sustainable Resource Development
Lee Charleson, Western Boreal Aspen Corp
John Doornbos, Canadian Forest Service
Tim Gylander, Weyerhaeuser Canada Ltd.
Sally John, Isabella Point Forestry
Chuck Kaiser, Alberta-Pacific Forest Industries Inc.
Jerry Klein, Forest Science Consulting
Ken Mallett, Canadian Forest Service
Florance Niemi, Daishowa-Marubeni International Ltd.
Donna Palamarek, Alberta Sustainable Resource Development
Jim Richardson, Poplar Council of Canada
Barb Thomas, Alberta-Pacific Forest Industries Inc.
Sandra Williams, Poplar Council of Canada
Francis Yeh, University of Alberta

In addition, financial support from several sponsors kept the conference affordable for attendees, supported the attendance of a student from each forestry school, and left us with a surplus after all the bills were paid. The following provided financial support for the meeting. We especially thank Alberta Sustainable Resource Development and the Northern Forestry Centre of the Canadian Forest Service for their support.

Agroponic Industries Ltd.
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Alberta Sustainable Resource Development
Beaver Plastics
Bonnyville Forest Nursery Inc.
College of Alberta Professional Foresters
Daishowa-Marubeni International Ltd.
Forintek Canada Corp.
K & C Silviculture
Monsanto Canada Inc.
Natural Resources Canada
Spencer-Lemaire Industries Ltd.
Weldwood of Canada Ltd.
Western Boreal Aspen Corp.
Weyerhaeuser Canada Ltd.

The very successful field trips were supported by Alberta-Pacific Forest Industries Ltd., Alberta Sustainable Resource Development, Weyerhaeuser Canada Ltd., and the Smoky Lake Forest Nursery. Entertainment at the barbecue was provided by the excellent Stumped blue grass band from Hinton. Meeting rooms, AV and IT assistance, and office support were provided by the University of Alberta. The conference logo was designed by Cindy McLaren.

Bruce P. Dancik

323 Treasurer's Report

The financial statement for the period of August 2000 to July 2002 was prepared by Treasurer Tannis Beardmore and tabled for information and acceptance by the membership (see Attachment #1). The statement shows a balance of $8,864.74 in the Association's account and GIC's totalling $24,000.00.

Motion: That the financial statement be accepted as presented.
Moved by: Dave Kolotelo
Seconded by: Leonard Barnhardt
Carried.

324 Financial Contributions

Agroponic Industries Ltd.
Alberta Sustainable Resource Development
Alberta-Pacific Forest Industries Inc.
Beaver Plastics
Bonnyville Forest Nursery Inc.
College of Alberta Professional Foresters
Daishowa-Marubeni International Ltd.
Forintek Canada Corp.
K & C Silviculture
Monsanto Canada Inc.
Natural Resources Canada
Spencer-Lemaire Industries Ltd.
Weldwood of Canada Ltd.
Western Boreal Aspen Corp.
Weyerhaeuser Canada Ltd.

Motion: That the CTIA/ACAA executive of the 28th meeting express our sincere appreciation to these contributors.
Moved by: Leonard Barnhardt
Seconded by: Sally John
Carried.

325 Editor's Report

The proceedings were printed and distributed during August 2001 to all active members, honorary members, Canadian universities and libraries, registrants, and financial contributors of the 27th meeting. Two hundred and forty proceedings were mailed.

A letter advising of the theme of the 27th biennial meeting, context of the proceedings, and a request for a 20 dollar donation to obtain a copy was sent to all corresponding members, USA addresses, and International addresses. As a result, proceedings were mailed to 5 Canadian, 12 USA and 27 International addresses. Eighteen copies remain on inventory.

The mailing list contains 526 addresses comprised of: 17 Honorary, 87 Active, 130 Corresponding, 70 Canadian libraries, 92 USA, and 130 International.

326 Education Committee

To promote students' knowledge and understanding in tree improvement activities and forest genetics research, the forestry faculties of Canadian universities were encouraged to nominate a student to attend the 28th CTIA/ACAA meeting. Sponsorship of these students is paid by the executive committee of each biennial meeting through registration fees. The following students received the award which provided all meeting costs including registration, accommodation, tours, and travel:

Todd Bonderoff	University of Northern British Columbia
Kirk Ellis	University of New Brunswick
Betty Pelgas	Université Laval
Jean-Francois Morin	Université de Moncton
Melanie Gentles	University of Toronto
Mark Lesser	Lakehead University
Kathryn Metcalf	University of Alberta

327 Working Group Reports

327.1 Tree Seed Working Group

The Tree Seed Working Group (TSWG) has published four editions of the News Bulletin (#32 to #35) since our last report. Ron Smith edited these New Bulletins, but has subsequently stepped down as editor. Thank you Ron for all of your efforts towards the TSWG. Dale Simpson has agreed to assume the role of editor.

In trying to promote the News Bulletin we have initiated themes as are indicated below:

#32 Tree Seed Testing
#33 Reproductive Biology
#34 Seed Treatments
#35 Legislation, Policies and Procedures

A workshop was held at the 28th CTIA meeting entitled "Genetic and Physiological Control of Seed Dormancy and Germination". The following presentations were made:

Dr. Allison Kermode	Physiological Control of Dormancy in North Temperate Conifers
Dr. Tannis Beardmore	Physiological Control of Dormancy in North Temperate Angiosperm Trees
Dr. David Gifford	The Breakdown and use of Seed Reserves in North Temperate Conifers and Angiosperms
Dr. Frank Sorenson	Adaptive Variation in Dormancy and Timing of Germination of Seeds of North Temperate Conifers
Dr. Yousry El-Kassaby	Genetic Control of Germination Parameters in North Temperate Conifers

Thank you to all of the speakers at our workshop.

A Business meeting of the TSWG was held and focused on the issue of a National Gene Conservation Initiative that was championed by Dale Simpson. The National Tree Seed Centre is looking to increase the provincial representation of species and provenances in their collection that is used for research requests and for gene conservation. Other issues raised at the meeting were Certification of tree seed and whether we should have National Guidelines for population sizes.

The TSWG eliminated separate working parties (Tree Seed Processing and Testing *and* Cone and Seed Insects) as they were generally inactive groups. These are important activities, but can be covered under the umbrella of the TSWG . The group has tried to maintain a TREESEED listserver to help promote the discussion of tree seed related questions. This has not been fully successful due to limited traffic and maintenance issues. We still hope to resurrect and promote the listserver as a means of exchanging information and obtaining a variety of opinions of tree seed related questions. We hope to present a more positive report on this activity at the next meeting.

In closing, I think it is appropriate to re-visit the objectives of the TSWG. The group began in 1983 with four objectives on <u>promoting tree seed science and technology through</u>:

Seed research from bud initiation to seed utilization;
Identification of seed problems relating to tree improvement and forest management;
Exchange of information on seed related problems;
Advising on implementation practices.

We look forward to all interested parties participating in moving these objectives forward.

Dave Kolotelo
Chair

327.2 Wood Quality Working Group

A wood quality/technology workshop was organized by the CTIA WQWG (Wood Quality Working Group) at its biennual meeting held in Edmonton, Alberta, July 22-25, 2003. The workshop theme entitled, "Integrating Wood Quality Attributes and End Uses with Sustainable Forest Management" had eighteen oral and four poster presentations, which was one of the fullest programs we have ever had for the WQWG. Most papers dealt with activities in BC and Québec, and covered four main subjects: 1) variation in wood quality attributes, 2) effects of intensive silviculture on wood quality and end uses, 3) utilization of managed fibre resource, and 4) incorporating wood quality and end uses into tree breeding programs.

Recently, several studies by Forintek on product quality attributes from genetically improved and/or intensively managed plantation resources in eastern Canada have led to a better understanding of products coming from this future resource. These studies point to the same conclusion that a high percentage of lumber pieces from the changing resource would not meet the current design requirements for lumber bending properties. These results underline an urgent need for incorporating selected wood quality attributes (e.g., wood stiffness) into current tree breeding programs that aim at sawlog production. As more and more tree breeding field experiments in Canada are developing more "mature wood," it may be time to evaluate wood quality and end-use potentials. Forintek will continue to work with the industry and governments across Canada to achieve this goal.

Wood property studies from the west that were reported at the workshop dealt with a variety of issues. These included papers on breeding for wood durability in western redcedar, the effects of site and disturbance on extractive content and wood density, to reviews of what fibre properties will be of value to the paper maker, in several species. As the forest industry in this country is shifting toward intensive forest management (IFM), and value-added wood utilization in recent years, increasing attention is being paid to wood and product quality. While it has always been difficult to know exactly what wood characteristics we should actively breed for, we are always in the position of needing to know what the interrelationships are among the various traits we are currently selecting for, with wood properties. The opportunity to discuss wood property assessment techniques, and strategies for improvement, was again an interesting and useful part of the CTIA over the years. The WQWG will attempt to maintain it activity at CTIA meetings to help facilitate the exchange of information and ideas between tree breeders and wood technologists.

Alvin Yanchuk
Tony Zhang
Co-chairs

328 Business Arising from Previous Meetings

328.1 Bursary (previous meeting items 317 and 305.2)

Michel Villeneuve presented a draft Terms of Reference at the 27th meeting. It was decided that the incoming Executive Committee would refine the draft terms and present them for approval at the 28th business meeting.

Motion: That a student receive an award for a presentation at a CTIA meeting.
Moved by: Michel Stoehr
Seconded by: Dave Kolotelo

Amendment to the motion: ... award for presentation and poster ...
Moved by: Sally John
Seconded by: Dave Kolotelo
Carried

Motion carried

A suggestion was made that a volunteer standing committee be created to elaborate on the criteria for the award, name of the award, and suggest names for judges. Awards were suggested to be $ 500 for a paper and $ 300 for a poster. Bruce Dancik and Michel Stoehr volunteered.

Motion: That the award be called the “Namkoong Award”
Moved by: Sally John
Seconded by: Greg O’Neill

The Chair pointed out that it is the standing committee’s responsibility to suggest a name for the award.

Motion: That the motion be postponed until the next CTIA meeting.
Moved by: Jerry Klein
Seconded by: Narinder Dhir
Carried

328.2 Official Gavel (previous meeting item 318.1)

Michel Villeneuve agreed at the last meeting to coordinate the crafting of a gavel using wood of improved species from each province. Unfortunately, Michel resigned from CTIA due to a change in employment duties. The Executive Secretary was instructed to write a letter to Michel to determine if it will be feasible to construct a gavel.

328.3 Name Change

There being insufficient members present, as per the Constitution and Bylaws, this item was not discussed.

329 New Business

329.1 Registration Requirements for Workshops

Dave Kolotelo pointed out that workshops are promoted and advertised as part of the CTIA meeting but attendees are not required to pay an additional registration fee. Expenses can be incurred when organizing these workshops such as subsidizing costs for a presenter to attend. It was suggested that since the Working Groups (Tree Seed and Wood Quality) are part of CTIA, the organizing committee should make money available to defray any costs incurred for any Working Group workshop. The Chair recommended that the Executive Secretary remind the Working Group Chairs to contact the Chair of each new Executive Committee if funds will be required for a workshop.

329.2 Constitution and Bylaws

Narinder Dhir noted that the current Constitution and Bylaws were adopted in 1973 and had been amended four times since. He felt it may be time to review the bylaws.

Motion:	That the incoming executive appoint a committee to review/update the Constitution and Bylaws.
Moved by:	Jerry Klein
Seconded by:	Narinder Dhir
Carried	

330 Future Meetings

330.1 Location of 2004 Meeting

At the 27th Meeting Dave Reid offered for the BC Ministry of Forests to host the 2004 Meeting. Dave Kolotelo agreed to confirm this with Dave Reid.

330.2 Location of the 2006 Meeting

Kathy Tosh and Howard Frame will evaluate the possibility of the three Maritime provinces hosting the meeting.

330.3 Location of the 2008 Meeting

Louise Corriveau agreed to investigate the possibility of holding it in Saskatchewan.

331 Election of New Executive

The following slate of officers will serve as the executive for the next CTIA/ACAA meeting:

Co-Chairpersons:	Dave Kolotelo and Dave Reid BC Ministry of Forests
Treasurer:	Tannis Beardmore Canadian Forest Service
Editor:	Dale Simpson Canadian Forest Service
Executive Secretary:	Dale Simpson Canadian Forest Service

332 Adjournment

Motion: That the 28th business meeting of the CTIA/ACAA be adjourned.
Moved by: Sally John

Attachment # 1

CTIA/ACAA
Financial Statement
August 2000–July 2002

Balance August 2000	**$39,893.15**

Credits

Interest (account)	$124.96
Interest (GICs)	$1,494.98
Purchase of proceedings	$661.30
Total Credits:	**$2,281.24**

Debits

Mailing envelopes	$162.15
Printing of 27th proceedings	$7,118.50
Bank charges for wire payments and conversion of foreign currency	$29.00
Advance for CTIA meeting (May 2002)	$2,000.00
Total Debits:	**$9,309.65**

Guaranteed Investment Certificates

GIC principal	$8,000.00
GIC principal	$16,000.00
Total GICs:	**$24,000.00**

July 2002:	
Cash balance	**$8,864.74**
Invested GIC balance	**$24,000.00**
TOTAL HOLDINGS	**$32,864.74**

ACTIVITY REPORTS

FROM ACTIVE MEMBERS

COOPERATIVE TREE BREEDING IN NOVA SCOTIA

Howard Frame and David Steeves

Department of Natural Resources
P. O. Box 68
Truro, NS
B2N 6P6

Keywords: *Picea mariana, P. glauca, P. rubens, P. abies, Pinus strobus,* seed orchards, breeding

The Nova Scotia Tree Improvement Working Group (NSTIWG) was established in 1977 and is the coordinating body for tree improvement in Nova Scotia. Active members include the Department of Natural Resources (DNR), Bowater Mersey Paper Company Limited, Kimberly-Clark Nova Scotia Inc., Stora Forest Industries, and J.D. Irving, Limited. The Canadian Forest Service has provided support services as well as technical and scientific expertise from the program's inception. Meetings are held in the spring and fall of each year to review progress and plans. Coordination is provided by the DN R. Species of interest include black spruce (*Picea mariana* [Mill.] BSP), white spruce (P. glauca [(Moench] Voss), red spruce (*P. rubens* Sarg.), Norway spruce (*P. abies* [L.] Karst.) and white pine (*Pinus strobus* L.). There are currently about 18 million trees planted annually in Nova Scotia.

CHANGES IN WORKING GROUP'S STRUCTURE

In the year 2000, the Province of Nova Scotia introduced new Forest Sustainability Regulations which restructured the method used to fund private land silviculture. Industries acquiring wood in Nova Scotia are now obligated to either fund or carry out silviculture on privately owned land. Their obligation is based on the amount of wood harvested in any one year. Seventy percent of the land base in Nova Scotia is privately owned. With this restructuring, came a dramatic reduction in the DNRs' tree improvement budget and subsequent reallocation of tree improvement staff to work with the implementation of the Forest Sustainability Regulations and wood supply analysis.

Industrial cooperative members were therefore required to step forward and take an even larger role in the day to day tree breeding activities formerly carried out by the DNR. With first generation seed orchards able to supply the current seed demand for reforestation within the province, the DNR does not plan to move forward with second generation orchard development at this time. The industrial cooperators, however, have all indicated a desire to proceed with second-generation breeding and orchard development.

SEED ORCHARD PRODUCTION

White and red spruce clonal orchards have consistently over-produced to the point where cones are often been left unharvested. Rogued firstgeneration black spruce seedling seed orchards are producing sufficient seed to meet the Province's reforestation requirements. Second generation black spruce orchards have not produced any significant amounts of seed. Clonal Norway spruce orchards produce crops on a regular basis, presumably in response to dry summers which have become the norm over the last five to seven years. Plans for 2002 include only harvesting cones from high breeding value clones in the orchards.

SELECTION AND BREEDING

In their expanded role within the Working Group, industrial members started "next generation" selection work on full-sib progeny in white spruce selection plantations. Individuals from approximately 20 crosses were graded and grafted in the winter of 2002.

Breeding work continued among the roughly 400 selections that make up the second generation black spruce breeding population. The additional 69 polycrosses made over the past two years brings this effort to 34% completion. Single-pair mating among these selections is off to a slow start with the addition of nine completions over the past two years for a total of 18.

As for the white, red, and Norway spruce breeding programs, the first generation white and red are complete. Norway spruce continues to be a challenge with only about 25 percent of the selections represented in polycross tests. The Norway spruce program was combined with the New Brunswick program in 1998 with breeding and testing shared between the provinces. It was jointly decided to use open-pollinated progeny for GCA testing in order to expedite this effort. The first series of open-pollinated progeny tests are scheduled to be outplanted in June 2002.

FIELD TESTING

Establishment of polycross progeny tests for white and red spruce is complete. This year, 2002, cooperators are outplanting the first black spruce realized gain test series. A second series of second generation black spruce polycross tests have also been sown for outplanting in 2003.

In 2000, eight year height was measured in the second red spruce polycross test series. Heritabilities were high (h^2_i = 0.23; h^2_f = 0.74) in comparison with those of the first series. Orchard roguing recommendations were made.

Eight-year heights were measured in 2001 in two white spruce and a red spruce polycross test series. These data have yet to be analysed.

BLUE SPRUCE IMPROVEMENT AT *PLANTSELECT*

**Robin Browne, Heidi Brown, Tammy Estabrooks,
Roxane Ledwidge, Vijaya Sharma and Ginny Thomas**

***PlantSelect* Biotechnology Systems Ltd.
101 Research Drive
Dartmouth, NS
B2Y 4T6**

Keywords: blue spruce, 'Misty Blue', somatic embryogenesis, clonal propagation

PlantSelect has been utilizing somatic embryogenesis (SE) as a means to screen blue spruce (*Picea pungens* Engelm.) seed collections. The general objective has been the identification and clonal propagation of elite material to supply nurseries specializing in woody ornamental plants. Of the original 170 lines first established, field trials have identified nine lines of higher quality after six years of evaluation. These lines are now in the process of larger scale production through SE and rooted cuttings from SE-derived stock plants. This has been followed by other initiation trials, the latest of which has involved seed of 'Misty Blue' (recognized for high incidence of blue needle plants). Aspects of ESM (embryonal suspensor mass) induction, cryopreservation, embryo maturation, and outplanting of 'Misty Blue' are described.

ESM INDUCTION

Of a total 2 528 embryos dissected from mature 'Misty Blue' seed, 743 were found to have initiated presumptive embryogenic tissue under inductive culture conditions (Table 1). Most embryogenic tissue was identified between 6 and 12 weeks in culture. The overall frequency of initiation was 29.4 %, well above the previous rates of 4–8% with other blue spruce seed sources. A total of 60 'Misty Blue' lines have been selected to establish proliferating ESM cultures for further evaluation.

CRYOPRESERVATION

To date, 18 of the 60 selected lines have been processed using our cryopreservation protocol. In general, viability appears good following freezing, with most showing 33–100% regrowth frequency (Table 2). This work will continue until sufficient frozen stock has been established for all lines.

EMBRYO MATURATION, GERMINATION AND OUTPLANTING

Concurrent with ESM proliferation and cryopreservation, the 'Misty Blue' lines are being tested for their capacity for embryo maturation, germination, and first stage outplanting survival. Standard culture conditions are being used throughout. There is considerable variation in response among lines, with some highly productive and others very low (Table 3). Loss of plants through the various phases can be considerable and this issue continues to be addressed in research to improve the SE system. Of the lines producing a sufficient minimum number of plants, field trials will be set up to study needle color, branch form, and other characteristics relevant to quality as landscape/ornamental plants.

Table 1. Initiation trials for 'Misty Blue' embryos in culture with respect to time on induction medium

Trial No.	No. embryos	No. embryos with embryogenic tissue						Total
		4wk	6wk	8wk	12wk	16wk	20wk	
1	49	0	0	3	5	0	0	8
2	126	0	0	61	15	0	0	76
3	171	0	67	24	4	0	0	95
4	170	0	14	38	9	0	0	61
5	205	0	6	21	7	0	0	34
6	215	0	17	51	10	0	0	78
7	229	0	49	17	47	0	0	113
8	245	0	33	38	0	0	0	71
9	200	0	11	9	4	2	0	26
10	263	0	30	14	6	7	0	57
11	256	0	18	4	4	0	0	26
12	200	0	37	5	11	0	0	53
13	199	0	29	11	5	0	0	45
Total	2 528	0	311	296	127	9	0	743

Table 2. Viability frequencies for cryopreserved select 'Misty Blue' ESM lines

Line	Viability (%)
MB11-16	0.0
MB07-18	0.0
MB06-75	100.0
MB05-73	100.0
MB11-23	33.3
MB10-49	100.0
MB09-62	33.3
MB04-01	0.0
MB06-11	33.3
MB08-25	33.3
MB06-41	0.0
MB07-46	33.3
MB09-67	66.7
MB13-22	66.7
MB09-65	0.0
MB10-39	100.0
MB06-65	66.7
MB06-50	66.7

Table 3. Embryo maturation, germination and outplanting survival of select ‘Misty Blue’ lines

Line	No. stage 3 embryos	No. selected germinants[1]	No. outplants[2]	No. surviving outplants
MB11-16	14	9	0	-
MB07-18	0	-	-	-
MB10-16	232	117	25	5
MB06-75	0	-	-	-
MB11-23	907	81	3	1
MB10-49	962	216	29	18
MB07-44	11	2	0	-
MB09-62	6	1	0	-
MB04-01	2104	1403	346	269
MB04-01	1536	978	252	206
MB06-11	309	122	9	6
MB06-11	183	81	13	10
MB06-31	803	525	146	115
MB06-31	413	297	96	75
MB08-25	0	-	-	-
MB06-41	398	90	16	3
MB07-46	0	-	-	-
MB09-40	196	81	4	1
MB10-39	0	-	-	-

[1] germinants of highest quality are selected following dessication and imbibition and transferred to germination medium

[2] germinants with epicotyl development are selected for outplanting

FOREST GENETICS, GENOMICS, BIOTECHNOLOGY AND TREE BREEDING RESEARCH AT DALHOUSIE UNIVERSITY

Om P. Rajora

Department of Biology
Life Sciences Centre
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Halifax, NS
B3H 4J1

Keywords: Molecular, population, conservation, and evolutionary genetics; structural and functional genomics; genome mapping, QTL mapping of growth and adaptive traits; EST, full-length cDNA and genomic gene-rich region sequencing, and gene discovery; differential gene expression in response to abiotic stress caused by global climate change and air pollution; SNP discovery and detection; microsatellite, AFLP, SNP, SCAR, and allozyme markers; genetic implications of forest management practices, forest fires and forest fragmentation; conservation, restoration and sustainable management of forest genetic resources; gene dispersal, mating system, spatial genetic structure and minimum viable population size; indicators of population viability; *Picea, Pinus* and *Populus*

During the past two years, our research activities continued primarily in the areas of molecular, population conservation and evolutionary genetics, genomics, phylogenetics, and breeding of forest trees. With the award of NSERC Strategic Project and Genome Canada Large-scale Project grants, our activities were significantly expanded in the structural and functional genomics aspects of spruce (*Picea*) species.

POPULATION AND EVOLUTIONARY GENETICS, PHYLOGENETICS, MATING SYETM, AND POLLEN GENE DISPERSAL

Studies on genetic diversity, population structure, and spatial genetic structure of eastern white pine (*Pinus strobus* L.) in old-growth (pristine) and second-growth stands in Ontario were continued (Rajora *et al*. 2000a). Vikram Chhatre is conducting his PhD studies, under my supervision, on pollen gene dispersal, mating system, and spatial genetic structure of eastern white pine from the contiguous and fragmented landscapes, using microsatellite DNA markers. The study on population genetic structure, variation and evolution of Engelmann spruce (*Picea engelmannii* Parry), white spruce (*Picea glauca* [Moench] Voss), and their putative natural hybrid complex in Alberta was published (Rajora and Dancik 2000). Studies on genetic diversity and population genetic structure of black spruce (*Picea mariana* (Mill.) BSP) from Manitoba (Rajora and Pluhar 2002; Rajora *et al.,* in preparation) and of white spruce from conifer-dominated and mixed-wood forests in Alberta (Mann *et al*. 2003), were completed. Intraspecific and interspecific genetic, phylogenetic, and evolutionary relationships were studied among *Populus* L. species and their interspecific hybrids (Cervera *et al*., in review; Rajora, in preparation) and among *Picea* species (Rajora *et al*., in preparation) based on microsatellite DNA and AFLP markers. A study on mating system and reproductive fitness traits of eastern white pine in large, central vs. small, isolated, marginal populations was completed and published (Rajora *et al.* 2002). A method was developed for estimation of actual inbreeding rates based on a combination of marker-based selfing rates estimated from filled seeds and inbreeding rates estimated from empty seeds (Rajora *et al.* 2000b, 2002).

MOLECULAR GENETICS

Highly informative microsatellite DNA markers were developed and characterized for white spruce and black spruce and their cross-species usefulness was determined in related spruce species: Engelmann spruce, Sitka spruce (*Picea sitchensis* [Bong.] Carr.), red spruce (*Picea rubens* Sarg.) and Norway spruce (*P. abies* [L.] Karst.) (Rajora *et al.* 2001). The cross-species transferability and usefulness of the microsatellite DNA markers developed from trembling aspen (*Populus tremuloides* Michx.) was determined in 24 *Populus* and two *Salix* L. species (Rajora and Rahman 2001). A study on microsatellite DNA somaclonal variation in tissue-cultured trembling aspen plants was completed (Rahman and Rajora 2001). Another study was completed on microsatellite DNA and RAPD fingerprinting and relationships of hybrid poplar (*Populus* x *canadensis*

Moench) cultivars (Rajora and Rahman 2002) and microsatellite DNA fingerprinting and relationships of clones, cultivars and varieties of six *Populus* species (Rahman and Rajora 2002). Postdoctoral fellow (PDF) Dr. Daoquan Xiang developed black and red spruce species-specific SCAR markers.

STRUCTURAL AND FUNCTIONAL GENOMICS

My research program at Dalhousie has focused primarily on the structural and functional genomics aspects of spruce species. The primary goal of this spruce genomics program is to utilize genomics technologies and tools to understand genome organization, to develop a gene sequence data base and genetic maps, and to identify, isolate and map genes and genetic factors controlling traits related to growth and adaptation to abiotic stresses, particularly those caused by global climate change and air pollution, in red spruce, black spruce, and/or their interspecific hybrids. The program is being conducted in collaboration with John Major and Alex Mosseler of Canadian Forest Service (CFS), Fredericton and Tom Noland of Ontario Ministry of Natural Resources and is funded by NSERC Strategic and Genome Canada Large-scale Project grants. Ishminder Mann (PhD student), Alok Gupta (PhD student), Dr. Daoquan Xiang (PDF), Dr. Yongzhong Shi (PDF), Dr. Joy Roy (PDF), Brent Higgins (Technical Assistant), Stephanie West (Research Assistant), and Taralynn Cluney and Waleed Abousamak (undergraduate students) have worked or continue to work on our spruce genomics project. I am recruiting several additional PDFs, graduate students, and research assistants to work on the spruce genomics project. The main research components of our spruce genomics program include: EST, full-length cDNA and genomic gene-rich region sequencing, and gene discovery; SNP discovery and detection; SNP, SSR and other EST-based marker development; genome mapping; gene expression profiling and identification of genes expressed differentially in response to abiotic stresses, particularly those caused by global climate change and air pollution; identification and mapping of genetic factors (genes and QTLs) controlling traits related to growth and adaptation to global climate change and air pollution (e.g., elevated CO_2 adaptation, drought tolerance, freezing tolerance, adaptation to elevated UV and ozone levels, growth, phenology, morphology, ^{13}C discrimination and other ecophysiological traits); and bioinformatics.

GENETIC IMPLICATIONS OF FOREST MANAGEMENT PRACTICES, FOREST FIRES AND FOREST FRAGMENTATION, AND CONSERVATION, RESTORATION AND SUSTAINABLE MANAGEMENT OF FOREST GENETIC RESOURCES

The studies in this area were continued on eastern white pine, white spruce, black spruce and red spruce. Genetic diversity impacts of shelterwood or seed tree harvesting systems were studied in old-growth and second-growth eastern white pine stands in Ontario (Rajora *et al*. 2002; Rajora *et al*., in preparation). A study was completed on determining genetic diversity effects of clearcut harvesting, forest fires and alternative natural and artificial regeneration practices in black spruce in Manitoba, using allozyme, ESTP and microsatellite DNA markers (Rajora and Pluhar 2002; Rajora *et al*., in preparation). Studies on genetic effects of forest harvesting and forest fires of different intensities in white spruce continue. This project is part of the large multidisciplinary EMEND (Ecosystem Management Emulating Natural Disturbance) project in northern Alberta. We have developed benchmark information on genetic diversity and population structure inherent in pristine old-growth white spruce populations as they occur in conifer-dominated and mixed-wood forest stands (Mann *et al.* 2003). In collaboration with Alex Mosseler, I completed studies on genetic diversity, population structure, mating system, reproductive and fecundity traits, and genetic effects of forest fragmentation or small population size in red spruce (Mosseler *et al.* 2000; Rajora *et al.* 2000b), eastern white pine (Rajora *et al.* 2002) and pitch pine (*Pinus rigida* Mill.) (in preparation). We have determined genetic and reproductive indicators for population viability in these species. Also, correlations between outcrossing rates, genetic diversity, stand density, seed traits, and/or parent and progeny performance were studied in red spruce (Mosseler *et al.* 2002).

ECOPHYSIOLOGICAL GENETICS

In collaboration with John Major, studies on intraspecific and interspecific genetic variation of several morphological, developmental, allometric and ecophysiological adaptive traits and their genetic basis in black spruce, red spruce, and their interspecific hybrids were completed (Major *et al.* 2003a,b,c).

TREE BREEDING

We produced advanced generation pedigrees (F_2, F_3, and back crosses) in black spruce and black x red spruce hybrids for genome and QTL mapping studies, in collaboration with John Major and Alex Mosseler.

ACKNOWLEDGMENTS

Financial support for the various studies outlined in the above was provided by NSERC research grants (Individual Research (Discovery) and Strategic), Genome Canada large-scale project grant, StoraEnso Chair's program, Dalhousie Graduate Student Scholarships, Canadian Forest Service, Manitoba Conservation-Forestry Branch, Manitoba Department of Natural Resources, Manitoba Model Forest Inc., Manning Diversified Forest Research Trust Fund, Canadian Forest Products Ltd., Tolko Manitoba Inc., Pine Falls Paper Company Ltd., and Louisiana-Pacific Canada Ltd.

PUBLICATIONS AND REFERENCES

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J. D. IRVING, LIMITED – TREE IMPROVEMENT SUMMARY

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Keywords: spruce species, jack pine, white pine, tree breeding, seed orchards, clonal propagation, somatic embryogenesis

STATUS OF BREEDING PROGRAMS AND ORCHARD PRODUCTION

J. D. Irving, Limited (JDI) participates in breeding and testing programs with the New Brunswick Tree Improvement Council (NBTIC) and the Nova Scotia Tree Improvement Working Group (NSTIWG) as well as operating independent testing programs. The company manages a total of 100 ha of clonal seed orchards including white spruce (*Picea glauca* [Moench] Voss) (first and second generation), black spruce (*Picea mariana* [Mill.] B.S.P.) (first and second generation), Norway spruce (*Picea abies* [L.] Karst), red spruce (*Picea rubens* Sarg.), jack pine (*Pinus banksiana* Lamb.) (first and second generation), white pine (*Pinus strobus* L.) and eastern larch (*Larix laricina* [Du Roi] K. Koch). Breeding and progeny testing associated with first generation orchards of white spruce, black spruce, and jack pine is complete and genetic roguing is in progress. The white pine breeding program was initiated in 1997 and initial polycross breeding is underway. Initial polycross breeding of the Norway spruce orchard selections was completed in 2001. Breeding and testing of red spruce is still underway and work with eastern larch is not a priority at present. Second generation orchards of black spruce and jack pine were established from selections made in NBTIC open-pollinated family tests and the breeding and testing work for these orchards is complete. Some preliminary genetic roguing is in progress. Establishment of a second generation white spruce orchard based on individuals selected in NBTIC full-sib tests and JDI diallel tests began in 2000 and final orchard selections will be established in 2002.

Annual reforestation stock production for the company is 18.5 million seedlings and seed orchards have been filling this requirement since the early 1990's for all species with the exception of red spruce. Continued effort to improve Norway spruce seed production has been effective with good cone crops during the 2000 and 2001 season. Vegetative propagation of controlled crosses of this species is proceeding. White pine improved seed is expected from our orchard in 2003. A seed orchard of red spruce was not established until 1992 and cone production has begun. Second generation orchard seed production for black spruce and jack pine increases each year. Since 1996, sufficient jack pine seed has been harvested to satisfy nursery stock production requirements. Production of second generation black spruce seed has nearly met nursery stock production requirements since 2000. The annual requirements for black spruce have been supplemented with first generation seed and vegetative propagation.

VEGETATIVE PROPAGATION AND TESTING

Although propagation of full-sib second generation black spruce families continues, emphasis has focused on crosses among tested first generation white spruce selections as well as crosses among white pine weevil resistant Norway spruce. Rooted cutting production is currently 1.3 million annually with future production increases anticipated. Preliminary growth data comparison of family bulking of rooted cuttings and seedlings of the same families has been analyzed.

Clonal testing programs were initiated with black spruce but now emphasis is on white and Norway spruce. Control-pollinated families are produced among tested individuals and clonal lines are initiated by somatic embryogenesis. The clonal lines are cryostored and sufficient somatic seedlings are produced for establishing clonal field tests. Approximately 250 to 350 clones are established in field tests annually. Five-year measurements of the initial black spruce field test were conducted in 2001. Groups of clones will be selected for operational production as more field test results become available.

NEW BRUNSWICK TREE IMPROVEMENT COUNCIL UPDATE

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Keywords: breeding, second generation, genetic gain, seed orchard, black spruce, jack pine, white spruce, tamarack

The New Brunswick Tree Improvement Council (NBTIC) completed its 26th year of operation in 2002. NBTIC has completed breeding and testing of first generation white spruce (*Picea glauca* [Moench] Voss) and tamarack (*Larix laricina* [Du Roi] K. Koch) and has started selection and breeding of second generation white spruce clones. Testing of second generation black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.) is almost complete with one more series of tests to be planted. First generation orchards are providing enough seed for all reforestation stock. Second generation black spruce and jack pine orchards have started to produce substantial quantities of seed and several second generation crops have been planted.

SEED ORCHARDS AND SEED PRODUCTION

Since 1978, seed orchards have been established by the industrial members of NBTIC who operate reforestation programs on freehold land as well as by the New Brunswick Department Natural Resources & Energy which is responsible for planting programs on Crown land. Over 130 ha of black spruce and jack pine seedling seed orchards were planted over a 10-year period ending in 1987. Clonal seed orchards, primarily of white spruce and tamarack, were also established over this time period, with over 60 ha planted.

Second generation orchard establishment of black spruce and jack pine began in 1989, with three agencies participating. Orchard establishment is now complete for these species with a total of 34.5 ha. The first planting of second generation white spruce orchards was started in 2000 with three agencies participating.

Seed production in 1999 was low, with a yield of only 8.1 million seeds from NBTIC agency seed orchards. Half of this seed was collected from first generation jack pine seedling seed orchards. As expected, cone production was up significantly in 2000 with almost 60 000 l collected. This compares with 5 300 l collected in 1999. The total seed production from all species was over 234 million seed. Black spruce and jack pine second generation orchards yielded 18 and 13 million seed, respectively. Cone production in the white spruce orchards reached an all time high of 37 000 litres collected in 2000. Seed yield was 158 million seed, the largest collection ever made in NBTIC seed orchards. Many of these white spruce first generation orchards have been rogued at least once while the first generation black spruce and jack pine orchards have been fully rogued for a number of years.

BREEDING

The Council completed a complementary polycross breeding program, which began in 1987, for white spruce and tamarack. The last series of white spruce tests was planted in 2001, another significant milestone for the Council. The last series of tamarack crosses was outplanted in 2002. Polycrossing of second generation black spruce and jack pine has made tremendous progress since the start of breeding in 1989, with 85% and 99% of the breeding complete, respectively. This is partly due to polycrossing *in situ* on the selections in the family tests as well as the considerable experience that Council members have gained over the 10 years of breeding work. Pair-mating of black spruce and jack pine commenced in 1994 and 1996, respectively, and will produce material for third cycle selections. This breeding is 56% complete for black spruce and 51% complete for jack pine.

The Council continues to follow the breeding strategy for black spruce that was adopted in 1993. Clones have been uniformly deployed to breeding groups and breeding is conducted in a positive assortative manner. A total of 15 sub-lines have been established for black spruce and 16 for jack pine. Breeding continues in the elite sub-line of black spruce and a clonal test from elite crosses was planted in 1999. Two series of full-sib jack pine and black spruce progeny tests were planted in 2000 and 2001.

SELECTION PROGRESS

Trees were selected in family tests for inclusion into the second-generation breeding population. Top performing families are identified based on 10-year height for black spruce and 7-year height for jack pine. Candidate trees were initially identified based on height growth, phenotypically graded in the family tests, and the final selection made from each family based on a combination of superior phenotypic and metric traits. A total of 402 jack pine and 411 black spruce clones were selected for the second generation population.

Second generation selection in white spruce began in the fall of 1998. The white spruce strategy is slightly different in that the selections originate from selection plantations laid out in 48-tree blocks. These selections are based on results from 10-year polycross progeny test measurements. A total of 133 of 420 trees have been selected to date.

TESTING AND DATA ANALYSIS

Testing continues to be an important component of the NBTIC program. Over the past 26 years, 291 tests were planted on over 346 ha. Over the past 14 years, progeny tests have been established to assess the performance of white spruce and tamarack plus trees and second generation black spruce and jack pine selections. Progeny testing of white spruce and tamarack will be completed by 2002, as well as the establishment of white spruce selection plantations from pair-mate breeding. Establishment of polycross tests of second generation black spruce and jack pine is 85% complete for both species.

The data analyst position has continued to be funded by the Council members. Over the past two years the data analyst, Bryce McInnis, has analyzed 10 progeny tests, 4 family tests, and 2 gain tests for a total of 16 tests. The results from 20-year test measurements have been used in a STAMAN Stand Growth Model to compare volume growth in Stand Tests and Family Tests. STAMAN is a computer model used in New Brunswick for developing yield curves. STAMAN uses data in the form of diameter and age-class stand-tables as a basis for ‘growing’ stands by periodic increments, to project overall stand development over time. Competition, mortality, site quality, and recruitment of new stems are all modeled by STAMAN.

For the Stand Test projections, over 13 000 individual black spruce were used to create STAMAN stand tables. For the Family Test projections, the top 25% of families from tests of over 26,000 individual black spruce were used. For black spruce, at age 40 the projected merchantable volume of the top 25% of first-generation material is 11% greater than the stand test material. These estimates of first generation genetic gain are conservative, because: 1) the material in the stand tests was of higher quality than would be found in average unimproved stands, and 2) STAMAN was calibrated using measurements from slower-growing wild trees and, at the time of this assessment, did not model the faster growth rates of improved material.

A second method of estimating genetic gain was by plotting and comparing mean height, based on field measurements of tens of thousands of trees from the tests. Height was plotted from age 5 to 20. The top 25% of families in the black spruce and jack pine tests were compared with the means from the stand tests. Height curves were projected linearly to rotation age (about age 40). This method indicated a rotation-age height gain of 7-8% for black spruce, which corresponds to a total volume gain of about 18-20%. For jack pine, a height gain of 20% was indicated. For both species, diameters of improved material were also larger than the unimproved material.

Both methods of estimating genetic gain were in agreement that the originally anticipated genetic gains of 10% per generation were conservative and will easily be attained.

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TREE IMPROVEMENT PROGRESS BY THE NEW BRUNSWICK DEPARTMENT OF NATURAL RESOURCES & ENERGY

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Keywords: cross-pollinations, progeny tests, seed orchards

The tree improvement program in NB is celebrating its 28th year of operation. Our efforts continue to focus on the main reforestation species, white spruce (*Picea glauca* [Moench] Voss), black spruce (*Picea mariana* [Mill.] B.S.P.), and jack pine (*Pinus banksiana* Lamb.). Interest in planting tamarack (*Larix laricina* [Du Roi] K. Koch) has diminished substantially in the past several years largely as a result of the European larch canker. Secondary species for tree improvement include balsam fir (*Abies balsamea* [L.] Mill.), Norway spruce (*Picea abies* [L.] Karst) and red spruce (*Picea rubens* Sarg.)

TREE BREEDING AND TESTING

The New Brunswick Department of Natural Resources & Energy (DNRE) is a member of the New Brunswick Tree Improvement Council (NBTIC), a group of cooperators including the federal government and six large industrial companies located in NB. All tree improvement work in the province is co-ordinated by the DNRE and all co-operators share in the workload.

In the past three years, we have continued to plant black spruce and jack pine progeny tests. One more series of progeny tests should complete second generation testing in both species. There are now over 350 seed lots planted for these two species, meaning we are over 85% complete.

Since 2000, three series of full-sib jack pine tests and two series of full-sib black spruce tests were planted. These test series came from full-sib crossing done within sub-lines established for each species. These tests will be used for making third generation selections in five to eight years. In 2001, the last series of first generation white spruce polycross progeny tests was planted. In 2002, the last series of first generation tamarack polycross tests was planted.

SEED ORCHARDS

All second-generation selections have been identified for black spruce and jack pine and, in 1998, we began selecting second generation material for white spruce. This is being done in selection plantations. One hundred and thirty-three trees have been selected. This will continue until we have made 420 or so selections.

In 2001, the white spruce first generation clonal orchards were rogued again, leaving 65 out of 99 clones in the orchards. We have continued to expand existing orchards and establish new ones. The table below summarizes orchard establishment.

Table 1. Seed orchards established by DNRE

Species	Generation	Type	Establishment Years	Area (ha)
White spruce	1st gen.	CSO[1]	1985-1987	9.0
	1st gen OV[3]	SSO[2]	1978-1982	8.6
	2nd gen.	CSO	2000-2002	3.5
Black spruce	1st gen.	SSO	1980-1987	32.0
	2nd gen.	CSO	1989-1997	11.8
Jack pine	1st gen.	SSO	1979-1986	25.0
	2nd gen.	CSO	1992-1998	7.9
Tamarack	1st gen.	CSO	1984-1986	8.0
Balsam fir	1st gen.	CSO	1990-1992	2.7
Red spruce	2nd gen.	CSO	1999	2.0
Norway spruce	1st gen.	CSO	1999	2.0
		SPA[4]	1998	2.0

[1] clonal seed orchard
[2] seedling seed orchard
[3] Ottawa Valley
[4] seed production area

CONE COLLECTION IN ORCHARDS

The second generation orchards are producing more and more cones. Below is a table showing the production in second generation orchards and what has been harvested from first generation orchards.

Table 2. Cone collection and seed yield from orchards in 1999 - 2001

Species	Orchard	1999		2000		2001	
		Cones (l)	Seeds (kg)	Cones (l)	Seeds (kg)	Cones (l)	Seeds(kg)
Jack pine	1stgen.SSO	2856	16.4	-	-	3494	20.9
	2ndgen.CSO	1181	7.9	2480	22.5	4077	38.2
Black spruce	1stgen.SSO	-	-	2120	19.2	-	-
	2ndgen.CSO	143	0.2	5786	15.5	85	0.3
White spruce	1stgen.CSO	-	-	18304	243.0	-	-
	1stgen.SSO	-	-	-	-	-	-
Balsam fir	1stgen. CSO	-	-	72	2.0	-	-

GENETICS, REPRODUCTIVE BIOLOGY AND SOMATIC EMBRYOGENESIS RESEARCH AT CANADIAN FOREST SERVICE – ATLANTIC FORESTRY CENTRE

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CONIFER REPRODUCTIVE BIOLOGY

R.F. Smith, J.E. MacDonald and J. Letourneau

Research in the conifer reproductive biology project continued to focus on both the physiological and molecular components of cone initiation and development. Several cone induction trials using GA were established and assessed to provide the materials required for a study on the molecular and anatomical characterization of developing black spruce meristems.

Two cone induction trials were conducted in each of 2000 and 2001 and weekly and/or biweekly shoot and bud samples from the 'flowering zone' were collected from 45 and 46 trees in 2000 and 2001, respectively. Ten collections were made in each year from all trees with a total of over 1 500 shoots sampled over the two-year period. Shoot/bud samples were frozen, freeze-dried, or fixed for molecular, growth hormone, and anatomical analyses, respectively. Cone counts from the year 2000 trials were made in 2001. Cone counts were made in the spring of 2002 for the 2001 trials.

EST libraries were obtained from buds from 'induced' and 'non-induced' sexually mature trees in the breeding orchard at Atlantic Forestry Centre (AFC). Approximately 4 500 ESTs from potential (pre-dormancy) seed cone and 4 000 EST's from vegetative buds have been sequenced and a preliminary comparison of the black spruce EST libraries to public databases was performed.

Post-dormancy buds were collected in the spring of 2002 during the early stages of shoot elongation. This material was used for constructing EST and SAGE libraries. We have sequenced approximately 2 000 ESTs from female post-dormancy buds and have in frozen storage, materials that could provide a comparable number of ESTs for each of male and vegetative buds from the same tree.

Approximately 20 000 SAGE tags from each of vegetative and female (post-dormancy) buds were produced. Clones containing a further 30–40 000 SAGE tags for each of these two libraries are currently in frozen storage pending possible renewed funding for sequencing.

Work on conducting full-length sequencing of selected flowering genes is a long-term goal of this project. Efforts to-date have been directed at trying to correlate the sequence information generated from ESTs and SAGE tags with similar genes from other species as identified in the public databases. We hope to produce approximately 50 000 SAGE tags from each of the tissue types. Depending on the level or redundancy observed, this may allow us to determine a first estimate of how many genes are being expressed in these tissues and an indication of the differential gene expression between vegetative and reproductive tissues.

One of the most fecund families, subjected to four cone induction treatments, was the subject of a detailed anatomical investigation of female cone development. Fixed bud material was processed into slide material and photographed under light microscopy. Digital micrographs of each bud were produced and detailed anatomical observations were made.

GENETICS OF GROUND HEMLOCK (*Taxus canadensis*)

R.F. Smith, S.I. Cameron, J. Letourneau, M. Duffy, D. Fleming, F. McBain-Hogg, C. McLaughlin, J. Phillips, P. Stewart-Leblanc and L.D. Yeates

Yew species throughout the world, contain a family of compounds called taxanes. These secondary plant products can be isolated from the foliage and roots of a number of different yew species for the treatment of cancer. First discovered in the bark of Pacific yew (*Taxus brevifolia* Nutt.) several of these taxanes are now in considerable demand for the production of anti-cancer drugs, the best known of these being Taxol®. The high value and significant demand for these compounds has resulted in considerable harvesting pressure on yew species worldwide. Demand for yew biomass has recently expanded to include ground hemlock (*Taxus canadensis* Marsh.). Ground hemlock represents what could be regarded as one of the last unexploited yew species in the world, but with the increase in the demand for paclitaxel and related compounds, the potential threat exists that *T. canadensis* may be over-harvested, as has happened elsewhere.

Since 1997, the Canadian Forest Service – Atlantic Forestry Centre has been engaged in a program to minimize over-utilization of ground hemlock by research in: 1) developing ecologically sustainable harvesting protocols in natural stands and 2) developing a domestication (tree improvement) program to identify and select elite cultivars of the wild species and develop them into a commercially reared crop.

To ensure the sustainability of the woodland harvest, yet accommodate the industrial need for reasonable biomass collection practices, a ground hemlock working group was formed with government, industry, and environmental NGO representatives. The Eastern Canadian Ground Hemlock Working Group has devised and agreed to harvest based on a set of minimum acceptable sustainable harvest standards. In a second group initiative, a series of collaborative research plots are being installed in 2002/2003 to assess different harvest practices.

The program to domesticate ground hemlock has five main elements:

1) Cultivar Selection: Over 1 325 genotypes of *T. canadensis* from throughout most of the natural range have been sampled and cuttings rooted. Range-wide nursery provenance trials are being established at four locations. To-date, approximately 1 000 clones have been planted in the tests with the remaining scheduled for the summer of 2003. In addition to evaluating growth of these clones, they will also be screened for taxane production. Promising plant material will be selected and propagated (initially by rooted cuttings) in a tree improvement program.

2) Nursery Propagation Using Rooted Cuttings: If a domestication program is to be successful, time must be minimized between the identification of elite plant materials and when large scale production is realized. Until such time that tissue culture is sufficiently developed, large-scale rooted cutting programs will continue to be required. We have conducted a series of trials on rooted cuttings which have examined the effects of: i) the time of year on rooting success, ii) the size of the cutting on rooting, and iii) rooting hormone on speed and percentage of rooting.

3) Intensive Nursery Culture: One of the objectives of our research is to determine how *T. canadensis* responds to intensive nursery culture. A series of fertilizer trials are being established. Results from these studies combined with those focusing on optimizing growing regimes will be used to develop and support operational-scale nursery production systems. These nursery trials are being established in cooperation with the New Brunswick Department of Agriculture, and Agriculture Canada on Prince Edward Island. Discussions are also underway with agriculture and forestry agencies in Québec and Ontario to establish companion plantings in those provinces.

Another study being conducted, is one in which plants are subjected to extended nursery growing seasons and intensive fertilizer and watering treatments with the objective of producing potted 'hedge' plants which will serve as donors for a large-scale rooted cutting program.

4) Tissue Culture: The main objective of the tissue culture research program is to generate elite clonal seedlings more quickly and in greater numbers than is possible through a rooted cutting program. Rooting cuttings of ground hemlock is both slow and expensive. Research in this area includes developing methods for somatic embryogenesis (SE) and developing a bioreactor/mini-container system to produce SE tissues and crops in bulk. Work to develop a method to propagate *Taxus* using bud and root tissues is also underway. Results from this component of the program are not yet available but some embryogenic tissue from both buds and seed has been obtained.

5) Methods to Increase Taxane Yields: For *T. canadensis*, productivity is not limited to assessing the total amount of dry weight matter per unit area per unit time. The objective is to maximize the amounts of taxanes

produced. Greenhouse, nursery, and growth chamber studies have been initiated to develop method(s) to increase the taxane content of crop plants (or harvested plant tissues). Two years of outplantings were established in 2001 and 2002.

SOMATIC EMBRYOGENESIS OF CONIFER SPECIES AND ITS APPLICATION IN CLONAL FORESTRY

Y.S. Park and I. MacEacheron

Conifer somatic embryogenesis (SE) is an important technology that could have a major impact on clonal forestry and tree improvement. In spruce species, including white (*Picea glauca* [Moench] Voss), black (*Picea mariana* [Mill.] BSP), and Norway spruce (*Picea abies* [L.] Karst.), SE technology is sufficiently refined to the point that it can be used in commercial tree improvement. This is because SE initiation and plant conversion rates are relatively high, although there is a large variation among genotypes. For example, we have achieved an SE initiation rate of about 65% using immature zygotic embryo explants and about 80% of these embryogenic clonal lines produce plants. However, there are still a number of problems in SE of pine species. Firstly, the rate of embryogenic tissue initiation is generally very low, with an exception of eastern white pine (*Pinus strobus* L.). Secondly, after embryogenic tissue initiation, obtaining mature somatic embryos for some species remains difficult.

In *P. strobus*, we obtained an optimized SE initiation protocol by manipulation of plant growth regulators, resulting in an initiation rate of 60% (Klimaszewska *et al*. 2001), but SE initiation in jack pine (*P. banksiana* Lamb.) still remains low, with only 17 and 18 new SE lines produced for 2000 and 2001, respectively. Because our optimized eastern white pine initiation medium (L-PGR) produced consistently good initiation rates, we were interested in testing this medium for other pine species. During the summer of 2001, we carried out two induction experiments involving Korean white pine (*P. koraiensis*) and Chinese pine (*P. tabulaeformis*). We obtained SE for both species, where no previous success in SE was reported.

It is well-known that the developmental stage of immature zygotic embryo (ZE) explants is important for SE initiation, with only a few days after fertilization being the most responsive stage. To extend the availability of these responsive ZEs, two cold storage experiments were conducted using 20 open-pollinated families of *P. strobus* in 2000. The first experiment involved storing cones at -3°C. The cones were retrieved weekly and subjected to an induction treatment. As expected, the percentage of SE induction declined as the length of the frozen storage period increased. The percentages of SE induction for fresh, 14, 21, 28, 35 and 42 days in frozen storage were 43.9, 26.3, 11.2, 7.3, 5.8, and 0.6%, respectively. The second experiment involved the storage of cones in a refrigerator at 3°C followed by induction treatment. The percentages of induction after 0, 7, 21, 40, and 100 days were 49.7 51.5, 51.2, 50.1, and 38.8%, respectively. These results indicate that eastern white pine cones may be stored in a refrigerator for 40 days without reducing embryogenic capacity. In some cases, refrigeration even stimulated SE induction. We were also successful obtaining SE from the cold-stored jack pine cones. Four of the 17 SE lines initiated in 2000 were from the cones stored for 21 days at 3°C.

The genetic integrity of clonal lines developed by SE is an important issue. It is a common phenomenon in pines that megagametophytes contain multiple archegonia, which are thus capable of producing multiple genotypes within a megagametophyte. As the megagametophytes are commonly used for SE initiation in pines, there is a possibility that an embryogenic clone contains multiple genotypes. During 2001, an experiment examining the integrity of SE clonal lines of eastern white pine using RAPD markers was begun. In the experiment, a random sample of 9 clonal lines was subjected to assessment. A total of 96 mature somatic embryos for each of the 9 clonal lines was produced and DNA was extracted from each embryo. The DNA samples were subjected to RAPD fingerprinting using 30 primers. The preliminary results show banding pattern variation among the 96 samples of a clonal line for some primers, indicating mixed genotypes within a clonal line. This result suggests that it is necessary to reinitiate SE from somatic embryos or initiate from immature zygotic embryos to obtain 'pure' SE lines. RAPD fingerprinting was also carried out for jack pine but no variant banding pattern was found. Since SE initiation in jack pine is a relatively rare event, it is likely that SE clonal lines originated from a single genotype.

The SE-derived trees of eastern white pine raised in 2000 (initiated in 1999) were planted as a nursery experiment at the Acadia Research Forest (ARF) in 2001. This clonal test included 100 clonal lines, planted in 6 replicates. The remaining jack pine and eastern white pine trees raised in 2000 (20 lines) were field planted as a demonstration plot at ARF. During 2001, an additional total of 150 clonal lines of eastern white pine were developed from the initiation experiment of 2000 and about 50 plants per clone were raised in a greenhouse for field planting, thus amounting to about 7 500 SE-derived trees. The greenhouse work was conducted in two parts, one in March and the second in June 2001. Also, 15 SE lines of jack pine (2000 initiation experiment) were raised in the greenhouse. The trees of these clones are in frozen storage for spring planting in 2003.

CONIFER SOMATIC EMBRYOGENESIS, EFFECT OF COLD TREATMENTS ON GERMINATION AND DESICCATION TOLERANCE

S.E. Pond

Research on germination of somatic embryos of conifers focused on improvement in the quality of germinated somatic embryos. Controlled, mild desiccation of mature white spruce somatic embryos (at -2 MPa) prior to germination significantly improved the quality of germinated somatic embryos. However, controlled desiccation requires specialized equipment, can handle only a limited number of embryos, and is labour intensive. Cold stress may result in similar stress responses as mild desiccation and was examined as an alternative method for improving germinant quality.

White spruce somatic embryos at four stages of development (globular, early cotyledonary, well formed with fully developed cotyledons, and fully mature) were germinated after exposure to temperatures of 1, 5, 10, 20 or 30°C for 0, 2, 4, or 8 weeks and the quality of the germinants was assessed. Growth of the embryos at a temperature of 10°C improved the overall quality of the germinants by stimulating rooting and decreasing hyperhydricity. The results (~ 70–80% normal germinants) compared favourably with results obtained from controlled desiccation of the embryos (~ 70–80% normal germinants). Growth of the mature embryos at a temperature of 5°C improved the quality of the germinants to a lesser extent (~ 60–70% normal germinants) but had the advantage of allowing short-term storage (8 weeks) of the mature embryos without any subsequent decrease in germinant quality. Temperature treatments are easy to apply and require no individual handling of the embryos. This study showed that germinant quality could be manipulated without a desiccation treatment simply by controlling the temperature at which the embryos are matured and when the temperature treatment is applied.

The ability to quickly and cost efficiently manufacture dried synthetic seed would make somatic embryogenesis in conifer species more commercially attractive. This requires an understanding of the mechanisms behind and optimization of: 1) development of desiccation tolerance during maturation, 2) prevention of imbibitional damage during rehydration, and 3) the ability to germinate the dried embryos directly in soil in the absence of a sugar source. Once an efficient system is developed to reliably produce embryos capable of withstanding the stress associated with desiccation and rehydration, then water free encapsulation methods can be developed for the dried embryos.

Work is progressing on desiccation and rehydration of conifer somatic embryos. White spruce somatic embryos were used as the model system. Cold storage of plates of mature (cotyledonary stage) white spruce somatic embryos at a temperature of 5°C for 8 weeks significantly improved their desiccation tolerance enabling them to withstand rapid air-drying in the direct airflow of a laminar flow hood (flash desiccation). This treatment produced 58% undamaged germinants with normal cotyledons, hypocotyls, and roots. Only 1% of the dried non-cold treated embryos germinated normally on germination medium (Pond *et al*. 2002). Cold storage is an easy method to increase desiccation tolerance as no special equipment is required, only a refrigerator. Flash desiccation in an airflow is a fast and easy method of desiccation. The cold treated air-dried embryos also showed less imbibitional damage if they were directly rehydrated on germination medium as compared to being rehydrated in a saturated atmosphere for 24 h (the current method used to prevent imbibitional damage) before being placed on germination medium. This suggests that direct sowing of dried synthetic seeds in soil is a possibility.

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GENETIC DIVERSITY AND GENE CONSERVATION RESEARCH AT CANADIAN FOREST SERVICE – ATLANTIC FORESTRY CENTRE

B.I. Daigle, K. Forbes, J. Loo, J.E. Major, D. McPhee, A. Mosseler and J.D. Simpson

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GENETIC DIVERSITY AND GENE CONSERVATION

J. Loo, D. McPhee, K. Forbes, J. Simpson, D. Crossland and C. Ramirez

Identifying priorities and developing conservation strategies has been the primary focus of the group for the past two years. The overall objectives are: 1) to develop and make available methods and strategies for protection of ecologically significant areas and rare, vulnerable, threatened or endangered species or populations, 2) to determine impacts of human activities on forest tree species composition in the Acadian Forest Region, 3) to assess genetic diversity of key tree species and develop gene conservation strategies when the need is indicated, and 4) to promote appropriate conservation measures for threatened forest species and representative forest ecosystems in Canada and internationally.

The group focuses primarily on four species: bur oak (*Quercus macrocarpa* Michx.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), American beech (*Fagus grandifolia* Ehrh.) and weeping piñon (*Pinus pinceana*). Donnie McPhee completed a masters thesis “The bur oak, *Quercus macrocarpa*, of New Brunswick: A species distribution and comparative genetic diversity study” at the University of New Brunswick (UNB) in 2001 under supervision of Judy Loo. He found that the genetic diversity of the small, isolated New Brunswick (NB) populations, mainly found around Grand Lake, was at least as high as that of other isolated populations and populations within the contiguous range of the species. NB populations had relatively higher levels of allozyme heterozygosity than the other populations.

Bur oak populations in the province appear to be healthy from a genetic perspective in spite of their small size and isolation but are threatened by cottage development and firewood harvest. The NB species range has declined substantially during the past 200 years to only a few thousand trees. On the basis of the genetic diversity study, he recommended a strategy including landowner education, protection of existing stands, and restoration planting using local seed to conserve the genetic diversity of NB populations.

Seed was collected from one Ontario (ON) and several NB populations and methods are being evaluated to try to extend the length of time for viable storage. Preliminary results showed that the ON seed stored for at least three years, packed in peat at 3°C, maintained more than 80% germination. NB seed has not stored as well. Experimental restoration plantings have been established on 10 sites, with generally high survival; most sites have greater than 80% survival after 4 years, providing an early indication that restoration is feasible.

Jamie Simpson completed a masters thesis entitled “Vegetative propagation of American beech (*Fagus grandifolia*)” in 2001 at UNB under Judy Loo’s supervision. American beech in Maritime Canada was first attacked by beech bark disease, caused by an introduced scale insect and *Nectria* fungus complex, more than 100 years ago. Since that time the beech component of hardwood and mixed-wood Acadian forests has declined and almost all trees have been damaged so seriously by the fungus that they have little ecological or economic value. Many hardwood stands include one or more beech trees that are disease free, however, and previous research has implied a genetic basis. Restoration of beech will include development of a vegetative propagation protocol, testing for genetic resistance, and determining the gene action conferring resistance.

American beech is not known to have been successfully propagated vegetatively, so objectives of the masters study were to determine whether buds from mature disease-free beech could be micro-propagated and plantlets successfully acclimated to the greenhouse environment and to evaluate factors affecting rooting of softwood root sprout cuttings of different ages. There was limited success with both micropropagation and cuttings in that plantlets with apparently healthy roots were produced and rooted cuttings were produced from sprouts induced in the greenhouse from roots collected from disease-free trees. Neither the plantlets nor the cuttings broke dormancy in the spring after over-wintering, however.

Experiments have continued, in collaboration with Marek Krazowski at UNB, with rooting and micropropagation, with the latter showing greatest potential. Seed from disease-free trees was germinated for use as grafting stock and for trials with the insect/disease complex to begin to study the gene action and mode of resistance in disease-free trees and to develop a protocol for production of disease-resistant trees. A new graduate student is expected to carry on this work in January 2003.

A genetic diversity study of eastern hemlock was initiated. The objectives are to determine the genetic diversity of mature populations throughout its Canadian range, concentrating primarily on the Maritime provinces and to compare the genetic diversity of mature trees with that of regenerating trees in these stands. Many stands are not regenerating well with some exhibiting serious decline symptoms.

Eight populations in NB, two on Prince Edward Island and six in Nova Scotia (NS) were sampled for needle tissue in spring 2002 and each mature tree was labeled and mapped for seed collection later in the year. Seed from the sampled stands will be collected for allozyme analysis and for storage in the National Tree Seed Centre for gene conservation. Genetic diversity of each of the individual trees represented in the *ex situ* collections will be known providing the capability for examining relationships between the diversity and number of filled seed, germination success, and other measures of population viability. Additional populations will be sampled in Québec and ON. Ecological data were collected from each stand, including diameter range of sampled trees, moisture conditions, frequency of regeneration, associated species, and presence of damage or die-back in sampled trees.

Carlos Ramirez, a PhD student, began working on a genetic diversity study of weeping piñon (*Pinus pinceana*) in fall 2001. Weeping piñon is an endangered species in Mexico with 20 known populations. Most of the populations are small and threatened by human activities. The degree of isolation and stand densities vary among populations. The study will focus on the relationships between population size, stand density, isolation, and measures of genetic diversity and variation using both allozymes and quantitative traits.

In addition, evaluation of human impacts to the Acadian forest since European colonization is the focus of a Masters project by Donna Crossland. Gaining an understanding of the changes in relative abundances and distributions of species during the past three centuries is useful in defining priorities for research and development of conservation strategies.

The group contributed to development of genetics indicators for a test and application of criteria and indicators in Chihuahua, Mexico. Judy Loo also taught a four week course entitled “Conservation Genetics” at the Colegio de Postgraduados in Montecillo, Mexico as part of an ongoing relationship with the Mexican university.

POPULATION VIABILITY ASSESSMENTS IN DECLINING TREES AND FOREST TYPES

A. Mosseler and J.E. Major

We continued with our efforts to develop and use various biological indicators to measure reproductive success, mating behavior, and genetic diversity to assess the viability of declining tree populations such as eastern white pine (*Pinus strobus* L.), pitch pine (*Pinus rigida* Mill.), red spruce (*Picea rubens* Sarg.), and Acadian late-successional, old-growth forest types. These studies are aimed at the potentially adverse impacts of certain forest management practices on the viability of populations and forest types at risk. Positive relationships between average stand age and size, and reproductive fitness and genetic diversity in red spruce indicate that late-successional, old-growth forest types may represent important reservoirs of genetic diversity. Relationships between stand structural features such as stem density of reproductively mature trees show a significant, positive relationship with reproductive success and genetic diversity. These findings have important implications for the management of residual populations following harvesting operations in species such as white pine and red spruce, which often occur in small, increasingly isolated, remnant stands. Maintaining a network of reproductively viable and genetically diverse stands may be especially important within an increasingly fragmented landscape where dispersal and gene flow among populations is necessary to minimize the effects of inbreeding and genetic drift and maintain the reproductive health of natural populations and their ability to function as suitable and adequate seed sources for natural regeneration.

INTRODUCTION OF PITCH PINE TO ATLANTIC CANADA
A. Mosseler

In 1994, seed was collected from across the Ontario range of pitch pine to assess the genetic and reproductive status of this rare and declining native species. Several genetic tests were established in Nova Scotia (NS) and NB. Based on the excellent growth performance observed in these tests, further testing of pitch pine will be expanded to other locations across the Maritimes in order to assess the climatic limitations and general adaptability of pitch pine and to compare its performance with native seed sources of jack pine (*Pinus banksiana* Lamb.) and red pine (*Pinus resinosa* Ait.) which will be included in these tests. A series of these genetic and species tests are planned for establishment in 2003 and 2004. The ultimate aim is to assess pitch pine as an alternative species for wood supply, carbon sequestration, and as a plantation nurse crop for restoration of native species and forest types, in both the Maritimes and central Canada.

ACADIAN ALTERNATIVE SILVICULTURE FOREST DIVERSITY PROJECT
J.E. Major and A. Mosseler

In 1999, a large 60 ha silvicultural impact test was established at the Acadia Research Forest to demonstrate the impacts of various forest harvesting regimes on biodiversity in general and on the maintenance of long-lived, shade-tolerant, late-successional species such as red spruce, in particular. Research on this site involves a multi-disciplinary approach where geneticists, entomologists, ecologists, and silviculturists are studying various aspects of harvesting impacts on biodiversity conservation. This larger biodiversity study provides the context for assessing a range-wide genetic sample of red spruce.

ADAPTIVE GENETIC VARIATION AND RESPONSE TO CLIMATE CHANGE
J.E. Major and A. Mosseler

Greenhouse gas levels are expected to double during this century and alter prevailing environmental conditions, which alter physiological components of tree productivity. It was hypothesized that there would be significant species X genotype interaction as a result of projected climate change. A number of studies have been conducted to examine the potential importance of species and genetic X atmospheric CO_2 and genetic X soil drought interactions in black spruce (*Picea mariana* [Mill.] BSP), red spruce and their hybrids using seed sources from across their sympatric range (Ontario (ON), NB, and NS). Significant results, for instance, show that freezing vulnerability increases under elevated CO_2 conditions and that red spruce seems particularly susceptible to damage. Also, red spruce allocates 40% more biomass to roots than black spruce.

GENETIC DIVERSITY, ADAPTATION AND CLIMATE CHANGE
J.E. Major, O. Rajora and A. Mosseler

This is a new initiative with the prime aim to utilize genomics technologies and tools to understand genome organization, develop gene sequence data base and genetic maps, and identify, isolate and map genes and genetic factors controlling traits related to productivity, adaptation to abiotic stresses, particularly those relevant to global climate and environment change in red spruce, black spruce (*Picea mariana* [Mill.] BSP), and black X red hybrids. We have produced highly unique pedigrees of spruce ideal for genome mapping, which have rarely or never been produced in conifers. This ideal material provides an unique opportunity for the proposed genomics work, especially for comparative genome mapping, sequencing of ESTs and gene-rich regions, identification of differentially expressed genes and proteins synthesized in response to climate change and other abiotic stresses, and QTL mapping of morphological and physiological traits related to abiotic stress adaptation. This will provide the foundation for future development of marker-assisted early selection for desirable traits.

NATIONAL FOREST GENETIC RESOURCES CENTRE
J.D. Simpson and B.I. Daigle

The Centre consists of three sections: National Tree Seed Centre, Organization for Economic Cooperation and Development (OECD) seed certification, and genetics experiment databases.

The Seed Centre's mandate is to provide seed of known origin and quality for research and to store germ plasm for *ex situ* conservation. An objective is to store samples from throughout the range of Canadian tree and shrub species. Staff have been active over the past two years collecting and processing seed, conducting germination tests, executing research trials, supervising students conducting research for theses, and providing seed for research. Staff are comprised of one professional and one full-time seed technologist supplemented with a summer student and occasional casual help. Seed collection continued to be an important activity with most of the work conducted in the Maritime provinces. Collecting has shifted from bulk to individual trees. Reasons for this include the tree-to-tree variation in seed quality, particularly for hardwood species, and requests from clients for this category of seed. Bulk collections are still made when appropriate or when opportunities present themselves. All collections are made in natural populations. During 2000 and 2001 about 330 collections were made from 46 species. In addition, the Seed Centre purchased seed and received seed through donation which amounted to over 840 seed lots from 38 species. Germination testing continued to be a priority in order to obtain current information on seed lot quality. Over 3 500 tests were conducted. The back log is slowly being tested. Requests for seed for research are received from clients from around the world. Over 80% of the requests are for seed from Canadian species. About 1 920 seed lots were shipped to researchers. A web site was completed which provides information about the Seed Centre and the seed lots that are available. The URL is www.atl.cfs.nrcan.gc.ca/seedcentre/seed-center.htm.

Developmental research continues to be conducted in order to determine the appropriate pre-treatment and/or germination conditions to subject seed to in order to promote complete and vigorous germination, to evaluate seed storage methods, and to improve seed processing techniques. For example, de-winging *Ulmus americana* and *Betula papyrifera* seed substantially improved germination by eliminating empty seed. Germination of freshly collected, winged *U. americana* seed was 89% but increased to 98% after de-winging. For *B. papyrifera*, average germination of winged seed from 18 seed lots was 37% but increased to 60% following de-winging. Floatation of *B. papyrifera* in 100% ethanol improved germination from 10% for winged seed to over 85%. The added benefit of these treatments is the reduction in seed storage volume. A storage experiment for *Pinus strobus* was initiated. Seed was collected from three trees from two populations, conditioned to three moisture contents plus a control, and stored at -20°C and cryogenically in the vapour phase at -145°C. After one year in storage, seed stored at -145°C germinated as well or better than seed stored at -20°C. The experiment is designed to allow for five more sampling times. Seed collected from individual trees in a natural population of *Picea glauca* and stored for 24 years illustrated the impact of storage temperature on long-term viability. Germination before storage was 96%. After 24 years in storage, seed stored at -20°C and 4°C germinated at 96% and 34%, respectively. An undergraduate forestry student conducted a senior thesis on germination testing protocols for *Acer pensylvanicum*. He used five seed lots and evaluated four durations of soaking, three periods of cold, moist stratification, and two germination temperatures. Results showed that seed soaked for 48 hours, chilled for 16 weeks, and germinated at 5/15°C produced an average germination of 92% (Bourgoin 2002).

The “OECD Scheme for the Control of Forest Reproductive Material Moving in International Trade” is applied to certify the origin of seed which is destined for the international market. The Scheme is a means to promote and facilitate international trade and movement of forest tree seed, plants, and vegetative propagules. Participation in the Scheme is voluntary. Certified seed carries with it a Certificate guaranteeing the provenance and implicit that all rules and regulations were followed in the collection and processing of the seed. Certification does not cover seed quality, i.e., germination. It is the seed dealer’s responsibility to have seed lots tested for purity, moisture content, and germination. The Scheme, which was adopted in 1974, consists of four categories of reproductive material: Source Identified, Selected, Untested Seed Orchards, and Tested. Certification work has been conducted almost exclusively in British Columbia because of the demand for seed from tree species located there. All OECD certified seed shipped from Canada has been in the Source Identified category. Guidelines have been written for registration of untested seed orchards but limited quantities of seed has been certified under this category. A new Scheme has been written to take into account progress being made in vegetative propagation and new techniques/types of seed plantations and seed orchards. Four categories of forest reproductive material are recognized: Source Identified, Selected, Qualified, and Tested. Under the Tested category, genetically modified propagules were included which unfortunately has resulted in a delay in the unanimous approval of the new Scheme by member countries.

Two databases containing information about genetics experiments established by the Canadian Forest Service in the Maritime provinces and Petawawa Research Forest are maintained and updated as trials are measured and managed/maintained.

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TREE IMPROVEMENT PROGRESS BY THE FOREST RESEARCH BRANCH OF QUÉBEC

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WHITE SPRUCE TREE IMPROVEMENT
André Rainville

In the first phase of the white spruce (*Picea glauca* [Moench] Voss) program, the clones used in the first generation seed orchards are evaluated in progeny tests. Genetic gain is maximized by collecting cones only from the best clones. With the establishment of twelve tests, the year 2001 saw the completion of most of the work in this phase of the program. The first five-year results were obtained for the Wendover orchard. Eight tests were also measured in 2001.

In the second part, the genetic value at age five of the first 100 trees selected in the first generation was obtained using measurements from five progeny tests established in 1997 which were the result of multiple crosses. Five selection plantations, established in 1996 and 1999, created from controlled bi-parental crosses between the same 100 trees, were also measured. The parents of the next generation will be selected in part from these plantations.

To complete the desired base population of 240 trees, the 140 missing trees were chosen among the 460 trees that were selected from single-parent progeny tests of the 1970s and 80s, based on height growth and wood density. The last parameter was evaluated over the last few years using increment cores. The selected trees were grafted and planted in a breeding orchard at the Pépinière de la station forestière de Duchesnay. Floral induction treatments were carried out in 2001 on the elite clones in order to be able to do controlled crosses in 2002 to evaluate the same parameters as in the preceding population (GCA and SCA).

On a more operational level, technology transfer to the provincial forestry branch responsible for seed and plant production was accelerated. The new seed transfer model, developed by Li *et al.* (1996) helped us redefine the areas where seed from the first generation white spruce seed orchards can be used. On a request from the forest industry, the sources of improved material that had been identified for southern Québec, were produced for evaluation in the north in the black spruce-sphagnum moss cover type.

NORWAY SPRUCE TREE IMPROVEMENT
Marie-Josée Mottet

The Norway spruce (*Picea abies* [L.] Karst) tree improvement program is being conducted by the Québec Ministry of Natural Resources in collaboration with the Canadian Forest Service (CFS). Three progeny tests resulting from pair mating breeding were established in the spring of 2000. Second-generation selections will be made from these tests and the best specific crosses will be used for the production of rooted cuttings. Specific crosses and polycrosses will be completed in future years.

Top-performing provenances and families have been identified from three open-pollinated tests conducted in the Appalachian Breeding Zone (Bas-Saint-Laurent/Gaspésie) based on 10-year height. For the best 26 out of 266 families, the genetic gain varies from 7 to 13%. Trees will be selected for inclusion in the breeding population and for establishing new seed orchards. For the Laurentides Breeding Zone, the three tests will be measured at age five in 2002, while for the Saint Lawrence River Zone, ten-year results will be available in 2003.

With the participation of Smurfit-Stone Corporation, five progeny tests are being established in 2002 in the boreal zone of the Gouin Reservoir area to evaluate their rusticity and performance. A collaborative study has been initiated with the CFS to examine the quality of timber from an experimental stand planted in 1969 at the Valcartier Forest Station. In light of the preliminary results, the authors concluded that in spite of its susceptibility to white pine weevil, Norway spruce can correct the distortions caused by the insect and has a high potential for producing quality timber.

JACK PINE AND SCOTS PINE TREE IMPROVEMENT
Roger Beaudouin

Eleven out of twelve seed orchards and four provenance trials established of jack pine (*Pinus banksiana* Lamb.) have now been rogued. The genetic gain at 10 years, calculated based upon the height of progeny in the orchards and thinned tests, varies from 1.9 to 7.2% when seeds are collected from all of the progeny in the orchards and tests. Initiation of the second generation of improvement began in 2001.

In 2001, 75 plus trees were selected from the progeny test and the first generation Chasseur jack pine seed orchard in order to set up new orchards and put into place improved populations for the second generation.

In 2001, dormant cuttings were taken from the lower branches of jack pine aged 6, 15, and 20 years. A rooted cutting trial was carried out at the Saint-Modeste rooted cutting centre (Rioux 2001). A second test will soon be established and the results will help us to better define second generation strategies for improvement and seed production.

In 2001, we identified the area where seeds will be used from ten first generation jack pine seed orchards and from other recommended sources according to the Mátyás and Yeatman (1992) transfer model. This model and the map of ecological regions of southern Québec (Saucier *et al*. 1998) were used to define the boundaries of the five jack pine tree improvement zones in Québec.

Several sites were identified and the visual symptoms of the loss of apical dominance of Scots pine (*Pinus sylvestris* L.) were described in 2000 and 2001. The results of foliar and soil analyses confirm there is a shortage of boron in the soil. Serious physiological diseases that are causing growth loss and poor tree form are likely due to this shortage. A forest research note on the subject is now in preparation.

BLACK SPRUCE TREE IMPROVEMENT
Mireille Desponts

Over the past few years, the general direction of black spruce (*Picea maraina* [Mill.] BSP) research was maintained. Clonal forestry continues to be the favoured approach for the introduction of new experiments: six tests of plants reproduced by cuttings were established.

Three new prescriptions for roguing seed orchards were prepared. Gains in height vary from 4.2 to 6.9%. The goal of producing seeds from each orchard requires a limit on thinning intensity. Software developed by the CFS to identify the areas where seed orchard seeds can be used, according to the locality of origin of the plus trees, was put into service in 2002.

Selection of elite trees continued in first generation progeny tests. The aim is to set up new seed orchards and to establish improved populations for the next generation. Cuttings from the selected trees are collected in July for propagation. The selection program will end in 2003 in all tree improvement zones.

Four progeny tests paired with two juvenile nursery tests were statistically analysed in order to validate the effectiveness of the juvenile tests in predicting the best progeny. These analyses will continue through to 2004, when nine other progeny tests, paired to three juvenile tests, will be measured. The juvenile nursery tests, maintained and systematically thinned, will serve several purposes, especially for reproduction studies and carrying out F2 controlled crosses or backcrossing for which the pedigree will be known for three generations.

LARCH TREE IMPROVEMENT
Martin Perron

In Québec, demand for hybrid larch (*Larix* spp.) has grown considerably since 1997 (195 000 plants). Demand will reach one million plants in 2003. In order to meet the demand and future needs, in 2001 we finalized the first stage of our new breeding strategy (2002-03) for European larch (*L. decidua* Mill.), Japanese larch (*L. kaempferi* [Lamb.] Carrière) and their hybrids. For the time being, selection of the best sources is being done and the 80 European larch and the 80 Japanese larch should all be grafted before 2005.

Moreover, demand for varieties of hybrid larch that are better adapted for reforestation in the boreal forest is constantly growing. In order to quickly confirm that European larch parents (1998 crosses) are adapted for vegetative propagation, we established one of the four progeny tests in 2001 (23 European larch and 16 hybrid progenies) in the balsam fir/white birch domain. Also, we have begun controlled crosses for Siberian larch (*L. sibirica* Ledub.), European larch, and Japanese larch in order to validate the best controlled crosses and identify the hybrids that are best adapted to the northern climate. Moreover, 100 trees were selected in our northern progeny test for tamarack (*L. laricina* [Du Roi] K. Koch) to produce the second generation.

Furthermore, from 2000–2002 we established seven clonal tests in three of Québec's ecological regions. The clones came from Laval University (Francine Tremblay's team). They were produced by somatic embryogenesis using seeds from crosses that were carried out in an indoor orchard from 1999 to 2001.

HARDWOOD TREE IMPROVEMENT
André Rainville

In 1998, the evaluation committee for the relevance of genetics and biotechnology research put an end to any new research by the Ministère des ressources naturelles on hardwood plantation silviculture and limited hardwood tree improvement activities. Thus, during the last two years, principal activities in tree improvement were limited to maintaining and measuring existing plantations, mainly red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britt.) provenance and progeny tests, as well as butternut (*Juglans cinerea* L.) conservation plantations. In hardwoods, pruning for form is considered essential to produce a quality tree. The approach used in these tests is to record the number of branches pruned for each tree, their position, and the percentage of foliage removed. The selection of the best material will, therefore, not only take into account tree growth but mainly tree quality related to the measure of the pruning efforts required to obtain this quality. The first analysis of these data is underway.

In 2000, however, given that seed production of white ash (*Fraxinus americana* L.) is both poor and erratic and that it took eight years to be able to collect seeds from several provenances, support was given to produce plants to establish eight provenance-progeny tests in Québec. Site preparation is underway and planting will be done in 2003. This project represents the basis of the new activities in hardwood tree improvement.

Lastly, a five-year assessment of work to conserve the *in situ* butternut gene pool was done. Phytosanitary inspections in the nursery gave evidence that the butternut canker can be spread by seeds and can infect plants from the time they germinate in the nursery. Decontamination treatments have been suggested. In 2000 and 2001, five years after establishment, inspections performed in the four conservation plantations revealed no symptom of the disease on trees.

SELECTION OF HYBRID POPLAR FOR DISEASE RESISTANCE
Marie-Josée Mottet

Work was done mainly by selecting clones resistant to Septoria canker using artificial inoculations. In the canker-conducive areas, only resistant clones are recommended for reforestation. The distribution of *Septoria musiva* is confined to southern Québec, mainly in bioclimatic domains 1 and 2 (sugar maple/hickory and sugar maple/basswood). Even though the conditions that favour the development of Septoria canker are little known, observations made in hybrid poplar experiments since 1969 indicate that bioclimatic conditions limit its spread further north. To evaluate the disease's potential for expansion, three experiments were established in domain 3 (sugar maple/yellow birch), one in 2000 and two others in 2002. Moreover, winter sunscald is also a serious problem in poplar plantations in all parts of Québec. A study was undertaken to identify the environmental factors involved and, eventually, to develop a method for selecting resistant clones. With this objective, two experiments were established, one in 2001 and the other in 2002, which will be monitored for ten years.

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RESEARCH ON TREE BREEDING IN QUÉBEC

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Keywords: pollen, mass pollination , seed orchard management, germination, seed, cuttings, vegetative propagation, *Picea glauca, Picea mariana, Pinus strobus, Larix decidua, Larix kaempferi*

This report summarizes results obtained since 2000 on tree breeding projects. Advances were significant in the areas of larch pollen storage and mass pollination (larches as well as spruces). With regards to rooted cuttings, optimizing the rooting of hybrid larch cuttings continues in close cooperation with the Centre de bouturage de Saint-Modeste.

SEED ORCHARD MANAGEMENT AND SEED GERMINATION
F. Colas

Pollen conservation

Mass pollination necessitates collecting very large volumes of pollen (1 to 2 litres per year, on average). These volumes require a large storage area and much handling. Using storage containers having a larger volume reduces labour and storage costs. After two years of storage, the viability of pollen remains steady, independent of the species (*Picea mariana* (Mill.) BSP, *Picea glauca* (Moench) Voss, and *Pinus banksiana* Lamb.) and the storage container used. We are also studying the storage of pollen harvested using a portable vacuum. We want to determine if this harvesting method influences the maintenance of viability. After two years of storage, the viability of pollen harvested using a vacuum is the same as pollen manually harvested.

Spruces (*Picea mariana* and *Picea glauca*)

We are continuing mass pollinations using an electrostatic pistol and are developing a trailer that will permit pollination to be carried out in an orchard on trees up to six m tall. Using screens of variable position and height, we are reducing the effect of wind during pollination and thereby minimizing the volume of pollen used. We are also continuing to study the length of the flowering period in our experimental orchard. This study is combined with trials designed to accelerate flowering in the orchard in relation to trees in the immediate area and thus limit pollen contamination.

Larches (*Larix decidua* Mill. and *Larix kaempferi* [Lamb.] Carrière)

Since 2000 we have been conducting a study on the flowering biology of the larches The objective of which is to develop simple methods that will produce good quantity and quality of hybrid larch seeds that will have a high germination rate. The trees used are potted grafts grown under shelter. Flowering of the grafts is regular and abundant for both males and females. We have developed a method of harvesting pollen that is rapid and inexpensive. Moreover, pollen can now be stored at least two years with no loss of viability, which is a tremendous advantage for the production of hybrid larch seeds, especially when European larch is used as the female. This will also be very useful for the larch tree improvement program because it allows for crossing that would have been impossible, especially when using pollen from more frost-hardy species like tamarack (*Larix laricina* [du Roi] K. Koch) and Siberian larch (*Larix sibirica* Ledeb.).

Germination of conifer seeds

Work on seed germination is being carried out in close cooperation with the Centre de semences forestières de Berthier. Since 1999, stratified white spruce and white pine (*Pinus strobus* L.) seeds have been delivered to nurseries, but their high water content creates constraints during seeding. We have undertaken seed drying trials following stratification in order to reduce water content and permit easier handling of seed lots. Though preliminary trials were conclusive, some germination problems were noted for white spruce in some nurseries during the 2001 seeding. Trials are continuing to perfect the drying method for stratified seeds.

VEGETATIVE PROPAGATION OF HYBRID LARCH BY CUTTINGS

D. Tousignant

The increasing interest by the forest industry for hybrid larch is based on its high growth potential. Because of the difficulty in producing seeds, the production of cuttings is the method chosen to grow hybrid larch plants from a limited number of improved seeds. After four years of work, the rate of rooting varies from 70 to 85%. Significant advances have been made: the determination of the growth regime to maximize cutting production (total of 140 to 170 cuttings per stock-plant), determination of the size of cuttings and of the phenological stage that favours rooting, and development and establishment of enclosures to use when doing cuttings operationally. During out-planting trials of cuttings, it was evident that the ageing of stock-plants influences the performance of cuttings because of the production of plagiotropic plants. Trials are on-going. In 2000, a project was iniated by the Direction de la recherche forestière to determine which containers are best adapted for the rooting of cuttings and to compare the performance of these seedlings in plantations (collaboration with B.-M. Gingras and M. Lamhamedi).

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RECENT ADVANCES IN TREE GENOMICS AND SOMATIC EMBRYOGENESIS

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INTRODUCTION

The last two years saw many new and positive developments. J. Bousquet was appointed to a senior Canada research chair (in forest and environmental genomics) and P.D. Khasa and J.J. Mackay joined the group as associate professors at Laval University. They came from the University of Alberta and the Institute of Paper Science and Pulp Technology of Atlanta, Georgia, USA,respectively. While J. Bousquet is responsible for structural and evolutionary genomics, he is sharing with P.D. Khasa the molecular population genetics program and P.D. Khasa is leading the molecular ecology program. J.J. Mackay is responsible for the functional genomics program and F.M. Tremblay is pursuing her research program in somatic embryogenesis and cell culture. During the last two years, the group welcomed several postdoctoral researchers, including C. Andalo (population genetics), V.-Q. Le (gene transformation), Y. L'Homme (molecular genetics), N. Madjidian (genome mapping), and M. Delalonde and A. El Meskaoui (somatic embryogenesis). Many graduate students were involved in the various research projects, including at the M.Sc. level J. Ayisso, I. Gosselin, M.C. Gros-Louis, P. Pollefeys, and S. Senneville and at the PhD level, C. Bomal, M. Bouillé, I. Gamache, D. Iraqui, J.P. Jaramillo-Correa, A. Navarro-Quezada, B. Pelgas, M. Perron, S. Plante, S. Richard, and R. Sibout. Several of these students were co-supervised by the adjunct professors J. Beaulieu, N. Isabel, and A. Séguin (all from the Canadian Forest Service, Québec)(CFS) and many of our publications reflect their involvement.

MOLECULAR POPULATION GENETICS AND ECOLOGY

Over the past two years, we pursued the study of the phylogeographic relationships between the hybridizing black spruce (*Picea mariana* [Mill.] BSP) and red spruce (*Picea rubens* Sarg.) (supported by NSERC). From scanning a large number of ESTP nuclear loci, we showed that the two taxa represent a progenitor-derivative species pair, with recent speciation during the Pleistocene (Perron *et al.* 2000). The genetic diversity of red spruce was reduced and was essentially a sample of that observed in black spruce. More recently, we developed a number of maternally-inherited mitochondrial markers in the genus *Picea* (Jaramillo-Correa *et al.* 2002). Recombination between maternally-inherited markers was observed in at least two species. These markers are being used to investigate the population structure of black spruce at the species margin in the north and to help decipher the population structure in the zone of contact with red spruce.

Using an enriched genomic library for single- or low-copy sequences and touchdown amplifications, we were successful in developing codominant and informative microsatellite markers in several forest tree species including subalpine larch (*Larix layallii* Parl.) and westen larch (*Larix occidentalis* Nutt.) (Khasa *et al.* 2000a, b; Rahman *et al.* 2000), white spruce (*Picea glauca* [Moench] Voss) and related species (Hodgetts *et al.* 2001), and dipterocarp species (Stacy *et al.* 2001). These sets of hypervariable markers are useful in breeding and genetic improvement programs, comparative genomics, molecular ecology studies, and management and conservation of genetic resources. For example, larch microsatellites are being used to depict the genetic diversity and population structure of western larch and subalpine larch and to estimate the genetic divergence and evolutinary history between the two closely related larch species (Khasa *et al.* in progress). With funding from NSERC and Ligniculture Québec and the collaboration of Forêt Québec (P. Périnet), poplar microsatellites and other markers are also being developed and used to assess the extent of introgression of exotic genes from plantations into the gene pool of native poplars (*Populus deltoides* Bartr.) and *P. balsamifera* L.) (Navarro-Quezada *et* al. in progress).

Using an unique set of populations/provenances in white spruce, we showed, with J. Beaulieu from CFS, what most molecular evolutionists have come to believe, that polymorphism at allozyme loci is essentially neutral, contrary to the variation observed in many quantitative traits (Jaramillo-Correa *et* al. 2001). Indeed, the patterns of variation at allozyme loci conform to neutral expectations and were identical to those observed at ESTP loci. Several other studies have been conducted. Notably, using ESTP markers, we showed that there were no differences in genetic diversity and mating system parameters between mature black spruce stands derived from seeds after fire and mature black spruce stands derived from pre-established layers after clearcut (Perry and Bousquet, 2001, funded by Network of Centers of Excellence in Sustainable Forestry).

With colleagues from CFS, we also showed that the genetic diversity of *Taxus canadensis* was much lower that its western ally *Taxus occidentalis*, with relatively strong population structure, as compared to most conifer species, suggesting a metapopulation structure (Senneville *et* al. 2001). Low genetic diversity had also been disclosed for the ecologically rare *Juglans cinerea* in eastern Canada (Morin *et* al. 2000). Other population studies, conducted with J. Beaulieu from CFS, aimed at modeling multivariate quantitative variation in black spruce and white spruce, in an effort to better predict adaptation and economic traits following various scenarios of seed transfer and climate change (Andalo *et* al. 2002; Beaulieu *et* al. 2002). These ongoing projects have been funded by the CFS and Forêt Québec.

FUNCTIONAL GENOMICS

We began establishing a functional genomics research program that will focus primarily on issues related to wood formation and properties (Mackay *et* al. in progress). A major initiative, funded by Genome Canada, is now getting underway that will focus on putative regulatory genes of secondary xylem (wood) formation in poplar and spruce, and defence response in poplar. We aim to test specific hypotheses regarding the function and role of several genes that are present in trees and for which homologues have been characterized, i.e. *Arabidopsis*. We will use these genes to help focus genome–wide analyses, which compared to single gene approaches, are expected to bring considerably more depth to the understanding of gene functions because of their comprehensive and systemic nature.

The primary objective of this large-scale project will be to establish a functional genomics analysis pipeline to test these candidate genes in conifers and poplar. This pipeline will rely upon two major genomic technologies: 1) gain-of-function/loss-of-function studies of regulatory genes by transformation of poplar and spruce and 2) large-scale microarray transcript profiling of transgenic lines and plants. Our pipeline for functional testing of candidate genes will also be supported by the four other axes of our program: 1) EST sequencing in spruce, 2) activation tagged lines for the discovery of regulatory genes in poplar, 3) comparative evolutionary studies of gene structure in *Arabidopsis*, poplar and conifers to shed additional light on the role of particular genes through an examination of structure-function relationships and population diversity, and 4) bioinformatics and statistical methods for microarray data analysis and mining.

This project is a joint effort of Laval University, the CFS, and Carleton University, with the collaboration of the Universtiy of Minnesota. We are also developing joint activities with other functional genomics programs in Canada, namely those at the University of British Columbia and Dalhousie University.

STRUCTURAL AND EVOLUTIONARY GENOMICS

In collaboration with N. Isabel from CFS, nearly saturated genetic linkage maps of white spruce have been completed (Gosselin *et al.* 2002) and work is well underway in black spruce using AFLP and ESTP markers (Pelgas *et al.* in progress). New codominant markers are being discovered using various techniques such as DGGE and SSCP (see Fournier *et al.* 2002). This work includes the developement of SNPs using various new strategies of DNA pooling and sequencing (Pelgas *et al.* in progress). In an effort to better understand the genome structure of spruces, these codominant markers will facilitate the establishment of consensus maps between pedigrees within species as well as between species (Pelgas *et al.* in progress). This joint project with the CFS is funded by the Canadian Biotechnology Strategy and a NSERC-genomic grant.

Our studies of molecular evolution at nuclear DNA loci in *Picea* are delivering exciting new results (Bouillé and Bousquet, in progress). Indeed, when estimating the gene phylogeny of sequenced alleles for various nuclear genes, species often failed to form coherent monophyletic groups. This pattern suggests rather long allele coalescence times beyond species divergence. This observation applies to allelic variation caused by indel polymorphisms (ESTPs) as well as by substitutions (SNPs). Such long allele coalescence time is indicative of historically very large population sizes in spruces and is likely to account for the high allelic diversity and heterozygosity observed at nuclear gene loci in spruces and more generally, in conifers. Another conclusion drawn from these studies is that nuclear genes are rather inadequate in estimating species phylogenies in *Picea*, and likely in other conifer genera. Current work involves estimation of the phylogeny of the genus *Picea* from several mitochondrial and chloroplastic DNA regions (Bouillé and Bousquet, in progress). This work is being supported by FCAR of Québec and NSERC. On another front and in collaboration with N. Isabel from CFS (Gros-Louis *et* al. in progress), we are developing nuclear and organellar diagnostic markers for the recognition of larch species and their hybrids, including RAPDs, ESTPs and SNPs, and their use in certifying hybrid progenies and in estimating the phylogeny of the genus. This work is being supported by Forêt Québec.

PHYSIOLOGY AND SOMATIC EMBRYOGENESIS

Various research projects have continued to focus on the somatic embryogenesis of white spruce, black spruce, Norway spruce (*P. abies* [L.] Karst) and hybrid larches, with financial support from Forêt Québec.

Our work on the effect of sucrose during the maturation of spruce somatic embryos was pursued. Briefly, we showed that the beneficial effect of an increased sucrose concentration in the maturation medium was caused by its complete and rapid hydrolysis under the enzymatic action of the cells. Furthermore, the experiments showed that sucrose, and later on glucose and fructose, were not utilized by the cells during maturation but might act on maturation mainly through an increase in the osmotic pressure of the medium. Recent investigations indicated that the effect of sucrose on embryo maturation is not linked to the osmotic pressure and that the presence of sucrose and of its hydrolysis during maturation is important (Iraqi and Tremblay 2001a). The positive effects of sucrose on embryo maturation and subsequent development into plants were related to an increased abundance of some storage proteins but not of the carbohydrate content of the embryos (Iraqi and Tremblay 2001b). In fact, our data strongly support a regulatory role of sucrose during embryo development. To understand the action of sucrose, apoplastic invertase in the tissues and extracellular invertase in the medium were characterized (Iraqi *et al.* 2002).

Our work on somatic embryo desiccation continued. We had shown that black spruce and white spruce somatic embryos can survive desiccation but that survival was dependent on the relative humidity treatment (Bomal and Tremblay 1999). An adequate control of water loss was also shown to be necessary to subsequent embryo germination. When water loss was well controlled, desiccated embryos germinated in a comparable way to fresh embryos. A protocol based on desiccation and cryopreservation of somatic embryos was also defined to allow long-term preservation of somatic embryos either for direct plant regeneration or for germplasm storage (Bomal and Tremblay 2000). More recently, we have shown that a partial water loss induces accumulation of sugars and dehidrins in the embryos therefore leading to desiccation tolerance (Bomal and Tremblay 2002).

The role of the *in vitro* gaseous micro environment was completed and we had found that a micro environment characterized by an accumulation of CO_2 and C_2H_4 and a diminution of O_2 promoted a higher production and uniformity of somatic embryos than a vented micro environment (El Meskaoui *et* al. 2000). Ethylene was further studied through the addition of either a promoter or inhibitor of this hormone as well as through C_2H_4 enrichment (El Meskaoui *et* al. 2000). Furthermore, the relationship of C_2H_4 and the capacity of embryogenic tissue lines to produce embryos was studied using black spruce embryogenic lines with different maturation capacities (El Meskaoui and Tremblay 2001). The analysis of C_2H_4 biosynthesis and that of its immediate precursor (ACC) together with the utilization of molecules known to alter C_2H_4 metabolism showed that C_2H_4 is implicated in somatic embryogenesis of black spruce and that the low capacity lines had excess C_2H_4 production.

Acclimatization of white spruce somatic plantlets was improved and characterized. We developed a new technique allowing acclimatization under *in vitro* conditions, therefore avoiding problems related to humidity control in the greenhouse. The plantlets acclimatized under this technique have been studied in terms of cuticular transpiration, photosynthesis, and ultrastructure (Lamhamedi *et* al. in progress).

Besides our work on somatic embryogenesis, a study was conducted where somatic seedlings from different clones were compared in morphology, growth, physiology, anatomy, and ultrastructure (Lamhamedi *et* al. 2000). Within the same family and under similar cultural and growth conditions, several clones differed significantly from the zygotic seedlings in height, root-collar diameter, needle dry mass, branch density, shoot and root dry mass, and length of needles. Microscopy showed differences in tannin distribution among clones while analysis of macronutrients N, P and K showed considerable variations within family in their use efficiency. Finally, since we had found several plants produced by somatic embryogenesis and exhibiting different types of somaclonal variation, we verified for the presence of mobile genetic elements in white spruce tissues. Reverse transcriptase sequences from Ty1-*copia* and integrase sequences from the Ty3-*gypsy* group were identified from the genome of white spruce and characterized (L'Homme *et* al. 2000).

GENE TRANSFORMATION

With the financial support of Forêt Québec, investigations were pursued to understand the factors involved in genetic transformation of white spruce. Using embryogenic suspension culture as a study system, different factors such as the culture conditions of the cells prior to bombardment and the age of the suspension were tested (unpublished). Previously, transgenic tissues were obtained and plants were regenerated. They are currently growing under greenhouse conditions for further testing. In parallel, a transformation protocol was developed using *Agrobacterium tumefaciens*, which led to stable transformation and plant regeneration from white spruce (Le *et* al. 2001). Presently, 1 400 transgenic white spruce plants, obtained from 14 independent transformation events with a construct containing a *Bt* gene, are growing in the greenhouse. The expression of *Gus* and *Bt* in these plants is under evaluation (J. Ayisso and F.M. Tremblay, in progress).

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RECHERCHE ET DÉVELOPPEMENT SUR LES INSECTES RAVAGEURS DES CÔNES ET DES GRAINES AU QUÉBEC

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Mots-clés: pyrale des cônes du sapin, scolyte des cônes du pin, *Bacillus thuringiensis*, écologie reproductive, phéromone sexuelle, insecticide biologique.

Les vergers à graines sont des sites propices pour l'établissement et le développement de populations d'insectes nuisibles. Ces ravageurs s'attaquent aux cônes et aux graines, entraînant ainsi une réduction significative de la récolte de semences servant à la production de semis génétiquement améliorés. La chaire de recherche sur les biopesticides du Dr. Claude Guertin s'est donc donnée comme mandat d'acquérir des connaissances et de développer des outils de lutte contre les insectes des cônes et des graines afin de limiter les dégâts occasionnés par ces ravageurs.

MÉTHODES DE LUTTE CONTRE LA PYRALE DES CÔNES DU SAPIN

La pyrale des cônes du sapin [*Dioryctria abietivorella* (Grote)], est un insecte qui occasionne d'importants dégâts dans les vergers à graines d'épinette blanche (*Picea glauca* [Moench] Voss) au Québec. En collaboration avec le Dr. Gary Grant du Service canadien des forêts, nous travaillons à l'identification de la formulation de phéromone la plus efficace pour capturer des mâles de pyrale des cônes du sapin. Cette collaboration nous a aussi amenés à travailler sur le pouvoir attractif de substances terpéniques sur des femelles de pyrale des cônes du sapin en période de ponte. Ces deux projets sont actuellement en cours et des résultats sont prévus pour la fin du mois de juin 2002.

Un autre projet sur la pyrale des cônes du sapin vise l'établissement d'un protocole d'utilisation du *Bacillus thuringiensis* var *kurstaki* (*Btk*) pour contrôler les populations de pyrale des cônes du sapin en verger à graines. Ce projet a pour objectif d'évaluer l'effet d'applications multiples de *Btk* sur la mortalité de ce ravageur.

CONFUSION REPRODUCTIVE CHEZ LE SCOLYTE DES CÔNES DU PIN BLANC À L'AIDE DE LA PHÉROMONE SEXUELLE

Le scolyte des cônes du pin blanc [*Conophtorus coniperda* (Schwartz)], est une menace pour la rentabilité des vergers à graines de pin blanc (*Pinus strobus* L.) au Québec. Une production exceptionnelle de cônes était prévue dans le verger à graines de pin blanc à l'Arboretum de Verchères en 2000. Pour limiter les dommages occasionnés par le scolyte des cônes du pin blanc, plus d'une centaine de capsules de phéromone ont été installées (superficie de 5,5 ha) dans le verger à graines. Très peu de dommages ont été observés suite à ce traitement et 353 hectolitres de cônes ont pu être récoltés. Par contre, l'absence de témoin dans ce dispositif ne nous permettait pas de confirmer si l'utilisation de phéromones était responsable des résultats obtenus. Pour palier à ce problème, en 2001 seulement un tiers du verger a été traité suite à l'utilisation de phéromones. Dix capsules de phéromone ont été installées uniformément dans le tiers le plus à l'est, en raisons des vents dominants. À la fin de la saison 80% des cônes sont demeurés intacts dans le bloc traité comparativement à 14% à 100 m à l'ouest de celui-ci. Une répétition de cette étude est présentement en cours de ce verger afin de compléter ce projet de recherche sur la confusion reproductive chez le scolyte des cônes du pin blanc.

WOOD QUALITY AND END-USE RESEARCH ON GENETICALLY IMPROVED MATERIALS

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Keywords: hybrid poplar, white spruce, larch, progeny trials, clonal trials, genetic variation, correlation, interaction, growth, wood quality, fibre morphology, decay resistance, veneer quality, lumber strength and stiffness, pulp properties

The Eastern Laboratory of Forintek is working on the improvement of wood and end-product quality for three species: white spruce (*Picea glauca* [Moench] Voss), hybrid poplar clones (*Populus* spp.), and larch (*Larix gmelinii* (Rupr.) Kuzen. and *Larix sibirica* Ledeb.). The overall objectives of these projects are to: 1) incorporate economically important wood quality traits into tree breeding programs, and 2) determine optimal end uses for genetically improved materials. These projects involved estimates of various genetic parameters for major wood and end-product quality traits and their implications for tree breeding toward both growth performance and quality end-products. In addition, end-use potential is evaluated for these genetically improved materials.

Our collaborators are: Jean Beaulieu, Canadian Forest Service (CFS); John Mackey and Jean Bousquet, Laval University; Pierre Perinet, Serge Morin, and André Rainville, Ministry of Natural Resources Québec; George Bruemmer, Tembec Inc.; Pengxin Lu and Bob Sinclair, Ontario Forest Research Institute.

WHITE SPRUCE

In collaboration with CFS, we initiated a large study on white spruce. A total of 290 trees was collected in 2001 through a thinning operation from provenance-progeny trials at two locations, Valcartier Forest Experimental Station and Lake St. Ignace. Both trials were established in May 1969. Each sample tree was divided into four parts: 1) an eight-foot butt log for lumber quality determinations, 2) a 20-cm thick disk used for the evaluation of basic wood properties and wood decay resistance, 3) an one-foot bolt for veneer quality study, and 4) an eight-foot log for fibre and pulp quality studies.

This project includes 5 sub-projects: 1) lumber bending strength and stiffness, 2) veneer quality, 3) pulp properties, 4) wood decay resistance, and 5) basic wood and fibre properties. We will estimate genetic variances, heritability, and genetic correlations for basic wood properties and quality parameters of different products. Genetic correlations of wood and product quality with growth will be determined. We will also test the genetic variation in wood decay resistance. By spring 2003, all sub-projects will be completed and we will start to write a number of scientific papers based on the results.

HYBRID POPLAR

In collaboration with the Quebec Ministry of Natural Resources, we examined wood properties and growth at two 3-year-old clonal trials located in Windsor and St-Ours, southern Quebec in 1997. In total, 371 trees of 21 hybrid poplar clones were sampled. Results indicate clonal effects on wood density and initial moisture content are stronger than growth traits. Selection for growth traits in hybrid poplar clones will not result in a significant reduction in selected wood quality traits. This study indicates that selection for stem dry fibre weight appears to be an optimal selection strategy. This selection criterion will achieve the highest genetic gain in stem dry fibre weight or maximum fibre production while wood density is improved.

Under the framework of “Ligniculture Québec”, another study will be undertaken on the same population in the fall of 2002. Based on the 10-year-old clonal materials from 4 sites, we will examine economically important wood and fibre quality traits and examine their correlations with growth traits. In addition, resistance of these hybrid poplar clones to three types of decay (standing tree decay, brown-rot decay, and white-rot decay will be studied.

LARCH

In collaboration with Tembec and Ontario Forest Research Institute, two larch species (*Larix gmelinii* and *Larix sibirica)* were studied for their wood properties and end-use potential. A total of 74 sample trees were collected from 21 families located in Kapuskasing, Ontario in the fall of 2001. Major wood quality traits have been assessed and their end-use potential for lumber and other solid products have been evaluated. In addition, Oriented Strand Board (OSB) will be examined. Because of limited numbers of trees per family, we could not estimate genetic parameters from these materials. Our focus was placed on comparing the two larch species and quantifying variation in wood properties among the families. Wood decay resistance will be tested as well.

ADVANCES IN FOREST GENETICS, GENOMICS AND BIODIVERSITY AT THE CANADIAN FOREST SERVICE, LAURENTIAN FORESTRY CENTRE

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Keywords: white spruce, *Picea glauca*, black spruce, *Picea mariana*, Norway spruce, *Picea abies*, eastern white pine, *Pinus strobus*, Canada yew, *Taxus canadensis*, butternut, *Juglans cinerea*, hybrid larches, *Larix decidua x L. kaempferi*, wood quality, warp, shrinkage, lumber, open-pollinated families, climate change, pedigree, ESTPs, AFLPs, microsatellites, RAPDs, SNPs, mtDNA markers, genomic mapping, species-specific markers

This report summarizes the progress of the Canadian Forest Service – Laurentian Forestry Centre's (CFS) research in forest genetics, genomics, and biodiversity for the period 2000-2002. Our activities mainly focussed on breeding work in three spruces (*Picea* spp.), eastern white pine (*Pinus strobus* L.), and Canada yew (*Taxus canadensis* Marsh.). We also continued to spend significant time in population genetics studies of forest tree species and in structural genomics in collaboration with J. Bousquet from Laval University (CRBF–UL). Research was also done in collaboration with our colleagues from Forintek Canada Corp. and Laval University on genetic variation and control of wood characteristics.

Research accomplishments were made possible with generous contributions of dedicated collaborators and staff who deserve our thanks. They are: René Pâquet, Daniel Plourde, Magella Gauthier, Jean-Paul Bilodeau, Yves Dubuc, Dominique Fournier, Manuel Lamothe, Susan Gagnon, Esther Pouliot, Sylvain Boisclair, Dr. Martin Perron, Dr. Christophe Andalo, Michèle Bernier-Cardou, Pamela Cheers and many summer students.

GENETICS OF INDIGENOUS SPRUCES

Jean Beaulieu

White Spruce

Over the last two years, we completed a study on geographic variation in kiln drying behaviour of white spruce (*Picea glauca* [Moench] Voss) lumber, in collaboration with Yves Fortin and Roger Hernández (Université Laval). Material was collected in a 36-year-old provenance trial located at Harrington, on a Bowater Pulp and Paper Canada Inc. property. Lumber was dried in an experimental kiln. Papers were prepared for publication in scientific journals and were given at international scientific meetings. A first paper focussed on estimating geographical variation in warp defects in lumber from plantation-grown wood (Beaulieu *et al*. 2001, 2002a). A second paper reported on the effect of two drying techniques on lumber quality as well as on variation in shrinkage and warping induced by drying techniques used (Beaulieu *et al*. 2002b). A third paper dealt with wood machining properties after kiln drying (Bustos *et al*. 2000a, 2000b; Hernández *et al*. 2001). We did not find any significant differences among provenances in shrinkage or warp. The same was also observed for wood machining properties. However, as a general rule, denser wood behaved better than light wood for shaping, boring, turning, and mortising processes.

In 2000, we initiated a study in collaboration with Tony Zhang (Forintek Canada Corp.), Paul Watson (Pulp and Paper Research Institute of Canada), and André Rainville, Ministère des ressources naturelles du Québec (MRNQ) to estimate genetic parameters of wood traits in order to develop a breeding program for growth performance and quality end-products. A genecological test, including 40 open-pollinated families from the Great Lakes-St. Lawrence region and replicated on two sites, was thinned in 2001. Two 210 cm logs were taken from each of the 320 trees sampled and transported to the Forintek Canada Corp. facilities in Sainte-Foy, Québec. Logs were then either processed into 2 x 4 studs or cut in sections for analysis of fibre or pulp characteristics. Evaluation of mechanical properties has begun.

Under my supervision and that of Jean Bousquet (CRBF-UL), Dr. Christophe Andalo, from Université de Paris XI, completed his postdoctoral work on studying the potential impact of climate change on adaptation of local white spruce populations (Andalo *et al*. 2000, 2001, 2002 submitted). Data collected from 41 seed sources in a provenance-progeny test replicated on four sites were used to develop models to relate growth and wood traits to temperature and precipitation variables. The models were tested using data collected in a second genecological test series and used to simulate the expected climate change. Wood traits appeared to be less sensitive than growth traits. With an increase of 4°C, we predict a 6% reduction in height relative to a seed source presently growing in simulated conditions. However, when a reduction in precipitation was simultaneously considered with warmer temperatures, the relative loss in growth was significantly reduced.

The evaluation of the performance, five years after planting, of a set of 150 full-sib families established in a farm-field test replicated on four sites was completed. The best families were identified and recommendations for repeating the controlled crosses to supply the Saint-Modeste rooted cutting centre were provided to the MRNQ. The genetic gain expected from bulking up the best 25 full-sib families is over 20%. A bilingual research note (Beaulieu 2002) was prepared to make the information available to a large audience and complete results will be published soon. Furthermore, as the farm-field test was completed, 8-year-old trees of the best families were transplanted by the MRNQ to create a second-generation seed and breeding orchard. Furthermore, cuttings were collected from 30 trees of each of 10 unrelated full-sib families and were rooted at the Saint-Modeste cutting centre. Over 15 000 rooted cuttings were obtained and they will be used to set up clonal tests and seed orchards.

The development of pedigree material continued. White spruce individuals belonging to F_1 families were induced to flower using gibberellin treatments in order to rapidly develop backcross and F_2 families. Due to the young age of the trees, the success of flower induction was limited and the work will have to be continued.

Black Spruce

In early 2002, we completed a project aimed at understanding the patterns of adaptive variation in black spruce (*Picea mariana* [Mill.] BSP) in Québec and delineating seed zones and transfer rules. This project was funded by the MRNQ and was carried out in collaboration with Jean Bousquet (CRBF-UL) and Martin Perron (MRNQ), as well as Francine Bigras (CFS). We set up a short-term retrospective trial on three sites using 90 open-pollinated families representing 30 seed sources. Growth and phenology traits were collected and analysed. Principal component analysis was carried out to summarise the variation observed among provenances using two principal components, which accounted for 79% of the total variation for all traits. Regression models were developed to relate the principal component scores to geoclimatic variables. The models were validated using a range-wide provenance trial established 25 years before the retrospective tests and were used to estimate the relative risks associated with seed source transfer. A GIS tool was developed to assist forest managers in their decision to move black spruce seed sources within Québec. A scientific publication was prepared to report the results obtained (Beaulieu *et al*. submitted) and technological as well as knowledge transfer was also made through oral presentations (Beaulieu 2001; Perron *et al*. 2000).

The development of pedigree material continued. Backcross, F_2 (self) and F_2 (intercross) families were obtained using controlled crosses. Vegetative propagation of these families (between 600 and 1 200 individuals per family) began in 2001, thanks to the collaboration of Michel Rioux from the Saint-Modeste cutting centre, and will continue during the next period.

POPULATION GENETICS OF FOREST TREE SPECIES

Jean Beaulieu and Marie Deslauriers

A study was carried out by Juan Pablo Jaramillo-Correa, a PhD student supervised by Jean Bousquet (CRBF-UL) and Jean Beaulieu, to compare the patterns of variation in quantitative characters and genetic markers using six regional white spruce populations (Jaramillo-Correa *et al*. 2001). We found that some phenotypic traits were correlated with geographic and bioclimatic variables, while variability in genetic markers was not and followed neutral expectations. Estimates of genetic diversity and population differentiation for 14 allozymes were essentially similar to those obtained with 11 ESTP loci. Variation among populations for some quantitative traits such as early height and wood density was greater than that for genetic markers, which suggests the presence of a strong adaptive response in quantitative traits. This contrasts with the absence of selective response observed for allozymes and ESTPs.

Research on the development of mitochondrial markers continued in collaboration with Jean Bousquet's laboratory. New primers were developed for non-coding mtDNA regions tested for their ability to direct DNA amplification in12 gymnosperm taxa and to detect sequence-tagged-sites (STS) polymorphisms within and among eight species of *Picea*. Indels and substitutions were observed for several loci, making it possible to distinguish among families, genera, and, in some cases, between species within genera. A scientific paper was submitted (Jaramillo-Correa *et al*. submitted). With our colleague Jean Bousquet, we also published results of research work of two graduate students we co-supervised with him. Senneville *et al*. (2001) showed that Canada yew populations were more differentiated than populations of most conifer species and that the level of genetic diversity was lower. A low level of genetic diversity was also reported for butternut (*Juglans cinerea* L.) (Morin *et al*. 2000).

A bilingual information leaflet (Beaulieu and Deslauriers 2002) was produced to make available knowledge on genetic diversity and population differentiation in white spruce as estimated with genetic markers and quantitative traits. A short synthesis on the potential impacts of forestry practices on the genetic diversity of boreal species was also produced (Beaulieu *et al*. 2002).

GÉNÉTIQUE DE L'ÉPINETTE DE NORVÈGE, DU PIN BLANC ET DE L'IF DU CANADA
Gaëtan Daoust

Au Québec, le programme d'amélioration génétique de l'épinette de Norvège (*Picea abies* [L.] Karst) est toujours réalisée conjointement avec la Direction de la recherche forestière (DRF) du MRNQ. M Ante Stipanicic de la DRF a pris sa retraite au cours de la dernière période et a été remplacé par Mme Marie-Josée Mottet de la même direction. Les efforts concertés des deux organismes sont déployés afin de poursuivre le programme entrepris dans le passé et basé principalement sur l'établissement d'un réseau de 9 tests de descendances (E390) distribués dans les 3 zones d'amélioration recommandées. Les 3 tests de la zone d'amélioration des Appalaches ont été mesurés en 2001, soit 10 ans après plantation, et les résultats devraient nous permettre de sélectionner sous peu les meilleures familles pour cette zone et de formuler des recommandations. Des gains génétiques atteignant jusqu'à 13% pour l'accroissement en hauteur ont été calculés chez certaines familles. Dans un des trois sites, les attaques causées par le charançon du pin blanc (*Pissodes strobi* Peck) sont très sévères et ont fait ressortir du matériel résistant originant de Hudson's Place et développé dans les années 70 par les généticiens de l'ancien Institut National Forestier de Petawawa.

Au cours de cette période, comme au cours des dernières années, beaucoup d'efforts ont été consacrés à relativiser les dégâts causés par le charançon du pin blanc aux plantations d'épinette de Norvège et de nombreuses présentations ont été faites devant des aménagistes et gestionnaires forestiers. Récemment, une étude sur la qualité des sciages obtenus d'arbres ayant souffert des attaques du charançon a été réalisée et présentée à la communauté forestière de la grande région de Québec. Ainsi il a été démontré, entre autres, que le rendement total en sciage ainsi que la qualité des produits se comparaient avantageusement à un échantillon provenant d'une plantation d'épinette blanche du même âge.

Un test clonal a permis à R. Lavallée du SCF de faire ressortir des différences importantes de susceptibilité entre les clones d'épinette de Norvège (E407). La phénologie, la croissance et la susceptibilité au charançon ont été observées par notre équipe dans un test clonal répété à 2 endroits et composé de plus de 150 clones. Ces données seront utilisées par S. Page pour son mémoire de fins d'études qui sera réalisé sous la direction de J. Bousquet de l'Université Laval.

Chez le pin blanc (*Pinus strobus* L.), plusieurs nouveaux tests ont été amorçés au cours de la période et visent: (1) à évaluer l'aptitude générale à la combinaison des sélections effectuées en milieu naturel et établies dans le parc d'hybridation de Cap-Tourmente (E601II); (2) à évaluer les aptitudes spécifiques de croisements effectués entre ces mêmes individus (E602); (3) à étudier les paramètres génétiques d'un dialèlle 6 x 6 (E603); (4) à produire d'autres espèces de pins haploxylons (E604) et (5) à produire les lots de semences hybrides obtenus par croisements au cours des dernières années (E605). Trois tests de la série E601 phase I ont été établis en milieu forestier dont 2 en collaboration avec la Forêt modèle du Bas-Saint-Laurent. Une conférence portant sur la l'amélioration génétique et la conservation du pin blanc au Canada a été préparée et présentée lors du dernier IUFRO WP 2.0215 Breeding and Genetic Resources of Five-Needle Pines: Growth, Adaptability and Pest Resistance qui a eu lieu du 23-27 juillet 2001 en Oregon.

Pour l'if du Canada (*Taxus canadensis* Marsh), une étude sur la variation et la sélection génétique pour le contenu en taxanes a été initiée en 2001. Ainsi 3 populations de Charlevoix, représentées par 50 individus chacune ont été échantillonnées et analysées. Des variations intrapopulations importantes ont été observées alors que les variations interpopulations n'étaient pas significatives. Des tests clonaux sont planifiés afin d'éliminer les contraintes environnementales et de confirmer les sélections préliminaires effectuées en milieu naturel. Ce projet est réalisé en collaboration avec la Société d'aide au développement de la collectivité de Charlevoix ainsi que Bioxel Pharma inc.

GÉNOMIQUE STRUCTURALE ET PHYLOGÉNOMIQUE

Nathalie Isabel

Au cours des deux dernières années, nous avons mis l'emphase sur la construction de cartes génétiques chez l'épinette blanche et sur l'élaboration de marqueurs génétiques de type ESTP (expressed-sequence-tagged-polymorphisms). Ainsi nous avons publié en collaboration avec J. Bousquet de l'Université Laval nos premières cartes génétiques d'épinette blanche (Gosselin *et al.* 2002). Ce travail a été réalisé dans le cadre du mémoire de maîtrise de Mme Isabelle Gosselin et financé par le CRSNG et la Stratégie canadienne de biotechnologie (SCB).

Nous sommes présentement à réaliser le même travail mais cette fois chez l'épinette noire avec des marqueurs AFLP et ESTP nouvellement élaborés (Pelgas *et al.* en progression) Les cartes obtenues nous permettront d'effectuer des comparaisons et d'étudier la synténie au niveau intraspécifique et interspécifique puisque plusieurs individus sont en voie d'être cartographiés chez les deux espèces d'épinette. Ce travail est effectué en collaboration avec J. Bousquet dans le cadre d'une subvention CRSNG-génomique.

Du côté du développement des marqueurs génétiques, nous avons mis au point des protocoles de révélation SSCP et DGGE (Fournier *et al.* 2002) pour les marqueurs ESTP. Nous travaillons également sur la mise au point de nouveaux marqueurs de gènes candidats basés sur la présence de SNP (Pelgas *et al.*, Lamothe *et al.* en progression). Tous ces nouveaux marqueurs nous permettront de dresser les premières cartes génétiques consensus chez les *Picea*. Ces travaux sont réalisés en collaboration avec J. Bousquet dans le cadre du doctorat de Mme B. Pelgas et sont financés par le CRSNG-génomique et la SCB.

Finalement, le développement de marqueurs diagnostiques (RAPDs, SSRs, ESTPs, SNPs) est également réalisé mais cette fois pour trouver des empreintes spécifiques pour les différentes espèces de *Larix* et leurs hybrides. Ce travail est réalisé par Mme M.-C. Gros-Louis, étudiante à la maîtrise, en collaboration avec J. Bousquet de l'Université Laval et est financé par Forêt Québec.

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MODELING AIRBORNE POLLEN DISPERSAL TO AID REDUCTION IN POLLEN CONTAMINATION

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Keywords: modeling, pollen dispersal, pollen contamination, gene flow, seed production, genetically engineered plants

Pollen contamination can significantly reduce the genetic quality of seed used for forest replanting, and ultimately, significantly reduce wood yield per unit land area. Significant resources have been directed to Ontario's tree breeding program in order to produce seed of high genetic quality. This report describes on-going work to reduce pollen contamination and thus maintain the high genetic quality of tree seed.

The purpose of this project is to develop a computer model of pollen contamination as caused by airborne pollen dispersal into seed orchards. Once successfully developed, the model can be used to optimize anti-contamination methods at orchards across Ontario, and if desired, further afield. This work was begun in the early 1990's with a series of field studies and developmental computer modelling efforts. In 2000, work was re-initiated with funding from Forest Genetics Ontario aimed at model development and application for a particular seed orchard.

Further extensive work was done on both the model and the processing of input for the model as well as an assessment of the field measured values. Assumptions made during model development in the early 1990's were tested and required modifications. Re-development with more rigorous assumptions indicated that the model generally over-estimated measured values.

An evaluation of all aspects of the work indicated that some further work is necessary in refining the model and possibly comparing model predictions against a second independent data set of dispersal data and dispersal model.

It is intended that these further model refinements and comparisons will be accomplished during a separate project funded by the Canadian Food Inspection Agency (CFIA). Work funded by CFIA will investigate the application of pollen dispersal models for the regulation of "plants with novel traits," including genetically engineered plants (including trees).

FOREST GENETICS AT THE ONTARIO FOREST RESEARCH INSTITUTE

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Forest genetics work at the Ontario Forest Research Institute (OFRI) was conducted in a number of areas since the last CITA meeting to serve forest genetic resource management and tree improvement programs in the province.

WHITE PINE GENECOLOGY AND COLD HARDINESS

P. Lu, B. Sinclair and D. Joyce

The short-term genecology study of eastern white pine (*Pinus strobus* L.) has reached its expectation. Final assessment of two farm-field tests, involving 112 natural white pine populations in Ontario, was completed in 2001. Consecutive 6 years growth data indicated considerable genetic variation in growth potential among geographic populations and that appreciable genetic gain can be realized through seed source selection for reforestation programs. Because of a latitude predominated clinal pattern of spatial variation and the significant reduction of growth potential when seeds are transferred from north to south, it was recommended not to use seed sources 1.5 to 2.0° latitude north of a planting site.

Additional cold hardiness assessments were conducted between 2000 and 2001 using artificial freezing tests with detached shoots and needles, as well as whole seedlings, to supplement the field trials that did not show differences among populations in frost hardiness, possibly due to relatively mild climatic conditions at the test sites. Freezing test data, indicated that under natural cold acclimation, eastern white pine populations in Ontario could tolerate considerably low temperatures in September through November that exceeded the long-term local low temperature extremes of the same periods. Implications of the study to seed source planning were that seed can be transferred north 1.5 to 2.0° latitude to promote stand growth while minimizing the potential for frost damage.

GROWTH AND ADAPTATION OF TWO EURASIAN LARCH SPECIES

B. Sinclair, P. Lu and M. Parsons

Species trials of *Larix gmelinii* (Rupr.) Kuzen. and *L. sibirica* Ledeb. were established across 6 sites in Ontario in 1981 by the Ontario Ministry of Natural Resources (OMNR) to test their growth and adaptation in the boreal forest. These trials were established using a replicated randomized complete block design and multiple-tree plots. Survival, height, and DBH were re-assessed in 2001 at 20 years of age. Log samples were also collected for a solid-wood property study by Dr. Tony Zhang at Forintek Canada Corp. and for a pulp and paper making property study through the collaboration of Dr. Paul Watson at Pulp and Paper Research Institute of Canada. Preliminary results from growth and adaptive traits indicated that the two species are well suited to grow in northern Ontario with superior growth rates as compared with several native species of similar ages. Site selection and vegetation management in the first 4 years after planting were, however, shown to be critical to ensure high survival and good growth.

SCREENING EASTERN WHITE PINE FOR BLISTER RUST RESISTANCE

P. Lu and R. Sinclair

Blister rust has been identified as one of the most devastating factors to cause regeneration failure of eastern white pine in Ontario. Breeding and screening white pine genotypes for blister rust resistance was a priority in the Ontario Ministry of Natural Resource between the 1950s and 1980s. A large number of putative resistant selections and interspecific hybrids were created and collected into several genetic archives during that period. The current project is to re-evaluate these genotypes following a more rigorous inoculation protocol using greenhouse seedlings. The first cycle of inoculation was conducted in 2001 to master the technique. More intensive inoculations are planned for 2002 and the next few years.

ENHANCING FIRST GENERATION PROGENY TEST PRECISION THROUGH SPATIAL DATA ADJUSTMENTS

P. Lu, P. Charrette and J. Lane

Most of the first generation progeny tests of black spruce (*Picea mariana* [Mill.] BSP) and jack pine (*Pinus banksiana* Lamb.) in Ontario are characterized with large numbers of genetic entries (up to 320 open-pollinated families) and, consequently, large block sizes for the randomized complete block experimental designs and multiple-tree plots. Environmental heterogeneity within a block was strong, showing various gradients and shapes. Traditional progeny test data analysis without spatial adjustment generally resulted in violation of statistical assumptions of independence and homogeneous variances, large genotype x environment interaction, low consistency of family rankings between sites, and lower heritability estimates. Spatial data adjustment methods suitable to the experimental layouts were compared for their efficiencies in improving experimental precision. Two data adjustment approaches (i.e., the moving-plot-average and post-blocking) were found to be operationally easily applicable and achieved more than a 20% improvement for the data under study as compared to those without spatial adjustment.

VEGETATIVE PROPAGATION OF JACK PINE USING PROLIFERATED DWARF SHOOTS

P. Lu and R. Sinclair

Rooting of jack pine cuttings using proliferated dwarf shoots (Browne *et al*. 2000) is under way at a relatively large scale in a greenhouse-misting environment after some earlier success in a growth room. The objectives of this study were to increase the rooting percentage and proliferation rates and to reduce the costs. Given the current difficulties in tissue culture of jack pine, rooted cuttings are expected to play some immediate roles in tree improvement.

WHITE SPRUCE PROVENANCE TRIALS AS INDICATORS FOR ASSESSING THE IMPACTS OF CLIMATE CHANGE

M. Cherry and W.H. Parker

This study is designed to examine the adaptability of white spruce (*Picea glauca* [Moench] Voss) to a changing climate, to add to our current knowledge about patterns of white spruce adaptive variation, and to assess potential stock deployment in current and future reforestation efforts. Twenty-one range-wide white spruce provenance trials, which were installed about 24 years ago, are being used as the basis for the study. Fifteen of the sites were jointly established in Ontario by the Canadian Forest Service (CFS) and OMNR. All populations at these sites were remeasured during 2001 for height, DBH, and survival. Previously collected data from an additional 3 sites each from both Nova Scotia and from Maine, provided by Dale Simpson (CFS), are also being utilized in the analyses.

Each population can be described in terms of the range of conditions it can tolerate and the conditions where performance is maximized. These descriptions of optimal performance for each population may then be superimposed upon predicted temperature changes as predicted from climate models and a prediction of where each population can grow best may then be made. By being able to predict where each population has the best chance of performing to its full potential, we may then be in a position to maximize carbon sequestration in this species.

Analysis currently underway indicates large genetic variability across the 21 tests. Quadratic transfer functions and response functions are being developed for test sites and provenances based on monthly climatic and geographic values. These functions vary and differ according to test location and population, but our findings show that they account for moderate to large amounts of the observed variation. Modelled geographic patterns of predicted seed source 'optimal' growth and climate values show seasonably-variable geographic patterns.

DEVELOPMENT OF FOCAL POINT SEED ZONES FOR WHITE SPRUCE IN NORTHERN ONTARIO

W.H. Parker, M. Cherry, J. Lane, K. Lennon, G. Breummer and P. Charrette

A companion study to the previously mentioned one is also underway which is investigating patterns of adaptive variation in white spruce seedlings. The study has additional goals including evaluation of rapid-growing southern sources of white spruce as a means to increase fibre production in northern Ontario, providing climate-based models of adaptive variation for white spruce that will allow appropriate adjustment of seed zones and breeding zones based upon predicted climate shifts, and development of an interactive GIS-based operational tool (Focal Point Seed Zone) for matching seed source to planting site. This tool will also be used to develop seed zones as well as providing the models needed to define breeding zones for white spruce. Focal point seed zone development requires complete seed source coverage, with all seed sources planted at all test sites. As seed sources in the existing provenance tests were not planted on all sites, those trials cannot alone provide the basis for this project since the coverage is not uniform.

Many of the same seed sources as in the previously mentioned provenance study are included in this project. Five field trial locations (Dryden, Thunder Bay, Geraldton, Kenogami Lake, and Chalk River, Ontario) were site-prepared in the summer of 2001. Seedlings were sown in January 2002. One hundred and thirty-two populations will be outplanted from the greenhouse to the field sites in summer 2002. The remaining seedlings will be maintained as greenhouse container stock for assessment of shoot phenology. Initial field measurements will be collected in the fall of 2002, with further growth and frost hardiness assessments continuing through to the fall of 2003. Traits being investigated were selected because they are excellent indicators of adaptive variation. For instance, local sources of white spruce at northern sites are often prone to frost damage from late spring frosts, but southern faster growing sources flush later than local northern populations, and therefore should undergo less frost damage than local sources when transferred northward. Late flushing also confers a certain level of resistance to spruce budworm.

OPTIONS FOR ALLOCATING AFFORESTATION STOCK IN ONTARIO WITH ANTICIPATED CLIMATE CHANGE

M. Cherry

Afforestation is being assessed in Ontario as one strategy which could be used to offset carbon emissions when accounting for total greenhouse gas emissions. A discussion paper was written which explored numerous complexities involved in choosing tree species and populations for afforestation programs, particularly in light of anticipated climate change. For instance, fast-growing trees may sequester more carbon in the short term, but not necessarily over a stand rotation. Block plantings require a land-use change, but sequester more carbon and are easier to monitor than scattered plantings. Under current predictions for climate change, the microsite of a seedling may change significantly during a tree's lifetime, presenting a challenge for stock deployment. Species and populations that exhibit phenotypic plasticity and are known to be broadly adapted to various environments are good choices for afforestation under expected climate change. An alternative strategy would be to identify populations having high levels of within-population variability and high heterozygosity. The paper also identified gaps in current knowledge about potential species recommended for afforestation, limitations of current climate models, and discussed the need for program incentives. More accurate predictions are needed of expected regional-level climate change, as well as subsequent species and population responses to climate change. A balance will be needed between carbon benefits gained from tree planting and competing resource use and conflicting land values.

Northwestern Ontario is expected to become warmer and drier over the next half century, with a general eastward shift in species ranges. Aspen may be well-suited to the driest sites, with white spruce and tamarack sequestering more carbon on sites where moisture is less of a limiting factor. In northeastern Ontario, many boreal and mixedwood species have high levels of genetic variability or are suited to varying habitats and thus are well suited to this region in the event of significant climatic change. Southern Ontario is expected to undergo warming and drying trends and some species extirpation may occur from the region should southern boundaries of their range recede northward. Southern Ontario's landscape and land ownership are highly fragmented, presenting additional challenges to afforestation efforts. Although northern Ontario has more and larger parcels of land available for afforestation, southern Ontario sites are more productive and can store carbon more quickly. Eastern white pine, red maple (*Acer rubrum* L.), and green ash (*Fraxinus pennsylvanica* Marsh.) are recommended for afforestation in this region under rapidly changing climatic conditions.

BUTTERNUT STATUS REPORT

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A status report on butternut (*Juglans cinerea* L.) is to be submitted to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2002, which is interested in listing butternut on the endangered species list. This species is being decimated throughout its range by the butternut canker (*Sirococcus clavigignenti-juglandacearum* V.M.G. Nair, Kostichka and Kuntz). Butternut canker is of unknown origin, but presumed to be an imported exotic. Devastation caused by the canker is so prevalent that butternut is at risk of extirpation in some regions of North America. The status report includes descriptions of butternut distribution, habitat, biology, use, and population trends, as well as a description of the canker and its interaction with butternut, in accordance with COSEWIC guidelines.

Upon submission of the status report, the focus in Ontario will shift to the development of a comprehensive butternut recovery plan, which will form a framework for appropriate species management, field testing, and educational delivery programs. Because much of the Ontario landbase upon which butternut can be found is owned privately, education and technology transfer are key to ensuring proper management and increased regeneration opportunities of this species within Ontario. Testing to screen for populations and individuals showing disease resistance, species genecology testing, and promotion of planting resistant stock will also be required and incorporated into a species management plan.

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TREE SEED ACTIVITIES AT THE PETAWAWA RESEARCH FOREST 2000–2002

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Keywords: species introduction, acclimatization, *Pinus banksiana, Pinus resinosa, Pinus strobus,* growth

There have been some changes in administration since the last CTIA report. In January 2002, the Petawawa Research Forest (PRF) became a component of the Great Lakes Forestry Centre at Sault Ste. Marie, Ontario and reports to Program Director, Bill Meades. Peter Copis retired from his position at the end of July 2001 after 29-years service with the Canadian Forest Service. His position was replaced by Dan Turcott but his genetics related service will not be continued, unfortunately.

The Canadian tree species introduction work with the Liaoning Provincial Academy of Forest Sciences in Shenyang, China has continued. Seed was supplied from the following species: jack pine (*Pinus banksiana* Lamb.), eastern white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.), white ash (*Fraxinus americana* L.), black walnut (*Juglans nigra* L.), and white spruce (*Picea glauca*). Visits were made by Steve D'Eon and Ben Wang in 2000 and Ben Wang in 2001 to give lectures and field visits of survival and growth performance of the introduced tree species from Canada. Our preliminary observations of this species introduction work were very successful and gratifying. The performance of both jack pine and eastern white pine was superior to the local pine species, *Pinus koraiensis* and *Pinus tabulaeformis* var. *rubescens*, after more than 20 years. A rough analysis of early results of the seed source trials showed that the PRF jack pine source (i.e., latitude 46°N) appears to be most suitable for Liaoning Province. These results confirm findings of an earlier report (Yu *et al*., 2001) on the introduction and acclimatization of five exotic pines in Liaoning Province. According to that report, all five introduced pine species including eastern white, jack, pitch (*Pinus rigida* Mill.), and ponderosa pine (*P. ponderosa* P.Laws. ex C. Laws.) from Canada (origin unknown) and Japanese black pine (*Pinus thunbergii*) had superior growth in height and diameter to the local indigenous pine *Pinus tabulaeformis* var. *rubescens* and normal phenological and morphological development after 80 years. The authors especially recommend eastern white pine from Canada as being the most desirable exotic species for Liaoning Province with beautiful form, superior growth and wood quality, resistance to a local insect, and multiple uses for reforestation and greening purposes.

The most recent family trials of various Canadian sources of jack pine in the western part (lat. 40°50'- 40°57' N; long. 124°44' - 124°57' E) of Liaoning province showed promising results. The planted 2+0 stock from Spoor Lake Seed Orchard in Algonquin Park, Ontario had 85% survival and vigorous height growth of over 3 metres after 5 years. Although family trials are still in progress, early indications of the two pine species of Canadian origin are promising and could be good candidates for large-scale planting in that province. While this work is still in progress, a new proposal for testing red pine has been proposed and several seed sources from the upper Ottawa Valley area were provided to the Academy in the spring of 2002. The Academy has already won several prestigious national awards for this co-operative project of Canadian tree species and seed source introduction and has received strong support from the Chinese Provincial Authorities. Early in 2002, a request was received from the Academy for assistance in procuring 100 kg of jack pine seed from an Upper Ottawa Valley source for large-scale planting. It just happened that there were two large jack pine harvesting operations in the Upper Ottawa Valley area (150 ha and 40 ha) where 200 hectolitres of cones can be collected to yield 100 kg of clean seeds. The collections will be registered with the Forest Gene Conservation Association, processed by the OMNR Tree Seed Plant in Angus, Ontario and provided to China as separate Forest Gene Conservation Association origin-certified jack pine seedlots.

Preliminary data analysis of a red pine seed yield study from the 2000 crop year was completed. A total of 304 cones from12 trees was sampled at PRF. The crown of each tree was divided into three sections vertically and up to 10 cone samples were taken randomly from each crown section. Cone samples were dissected for detailed cone analyses according to Lyons (1956). A summary of the preliminary results is shown in Table 1. There were 2 081 healthy cones produced by the 12 sample trees with an average of 173.4 cones per tree. Based on a survey of five trees, the general distribution pattern of the cones in the crown appeared to be 75%

in the upper, 20% in the middle and 5% in the lower crown section. It is interesting to note from the results that the average number of seeds per cone in the upper crown (38) was higher than that of the middle (34) and lower crown (30), although the number of filled seeds and seed germinability were lower.

According to the Ontario Tree Seed Plant (OTSP) records, there was a significant decline in viable seed yield per hectolitre of cones of the major reforestation species in 1996–1999. Red pine seed yield decreased by 47%. One of the objectives of the Petawawa study was to confirm the decline in seed yield and to identify the causes of it.

Table 1. Summary of seed yield and seed quality of 12 red pine trees from year 2000 crop at PRF

Crown section sampled	Sample size	Cone length (mm)	Cone width (mm)	Total seed per cone	Filled seed per cone	Filled seed (%)	Germinability (%)
Upper	111	49.1	27.4	38	22	58	78.5
Middle	109	47.1	26	32.8	29	88	84.8
Lower	84	44.8	24.2	31.2	27	89.7	84.2
AVERAGE		47	28.9	34	26	78.6	82.5

Based on our study results of the year 2000 red pine crop at Petawawa, the seed yield per hectolitre cones (3 640) is 936 g clean seeds as compared to the OTSP's operational seed yield of 427 g and OTSP's past record of 750 g. If the current OTSP's red pine seed yield is compared with OTSP's past record and the current Petawawa results, there is a reduction of 43% and 54%, respectively. Upon careful examination of the 1996–2001 OTSP processing records, there were great variations in seed yield of red pine among seed lots and cone crop years. This seems to suggest that these variations in seed yield could be caused primarily by cone quality. Past records also indicate the importance of collecting seed only in good crop years to ensure not only the maximum seed yield at lower cost but also the highest genetic and physiological seed quality. Although the high seed yield from our study results was based on manual seed extraction and should be treated as the maximum potential yield, it does point to the possibility for further improvement in operational processing efficiency.

Ben Wang delivered a lecture on seed quality at the Forest Gene Conservation Association sponsored Certified Seed Collector's Workshop in Kemptville, Ontario and presented a keynote paper on the "Control of seed quality in reforestation and afforestation" at the International Tropical Forestry Symposium in Taiwan. He conducted a project review for the National Tree Seed Centre and the National Forest Genetic Resources Centre in the Canadian Forest Service - Atlantic Forestry Centre (CFS-Atlantic) in Fredericton, NB, reviewed manuscripts for colleagues of other organizations, and made contributions towards manuscripts with other authors.

Red pine foliage and seed material from a red pine natural regeneration experiment was collected and forwarded to Daya Dayanandan at Concordia University for DNA analysis. The 410G white spruce trial was remeasured by Marilyn Cherry of Ontario Forest Research Institute (OFRI) and Bill Parker of Lakehead University as part of their project on developing focal point seed zones for white spruce. Foliage was collected by PRF crews and forwarded to OFRI for frost hardiness testing. Alex Mosseler and John Major (CFS-Atlantic) continued their work at the PRF on white spruce, black spruce (*Picea mariana* [Mill.] BSP), red spruce (*P. rubens* Sarg.), and white pine. The white pine nursery test was remeasured and thinned in 2001. Controlled crosses of black spruce were undertaken at two locations. Cones were collected from the red spruce provenance trial. Phenological measurements were made for budburst date for the 410G white spruce trial and for the white spruce nursery trial. Observations of peak pollen release dates were made for major species to continue the record started in 1951. Observations of cone crops were made to continue the record started in the 1930's and seed traps were placed in two pine stands in both 2000 and 2001 to quantify seedfall under different management regimes. A graduate student from the University of Illinois, Lynn Anderson, collected white and black spruce foliage for DNA testing in her research on the evolutionary history of these two species.

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MANITOBA'S TREE IMPROVEMENT PROGRAM

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Keywords: jack pine, black spruce, white spruce, genetic diversity, AAC determinations, hybrid poplar

Manitoba Conservation – Forestry has established tree improvement programs for the three main coniferous reforestation species: jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* [Mill] BSP) and white spruce (*Picea glauca* [Moench] Voss). The major forest companies, Tolko Manitoba, LP Canada Ltd., and Tembec Forest Resources, cooperate in some of these programs within their Forest Management Licenses (FML's). A Tree Improvement Trust Account has been set up to allow cost sharing for work completed in these co-operative breeding zones. This report will highlight the major activities completed in the past 2 years. These are in addition to the on-going activities at test and orchard sites including competition control through mowing, brushing and Vision application, and orchard fertilization and foliar nutrient analysis.

JACK PINE

Cone collections were conducted at the Hillside pedigreed orchard in the Eastern Breeding Zone producing 10.5 kg of seed. Cone collections were also conducted at the Northern and Interlake mass selection seed orchards producing 4.56 and 2.98 kg of seed, respectively. These orchards meet the seed requirements for reforestation in their seed zones.

BLACK SPRUCE

Height measurements were conducted at the Spruce Siding family test in the Southeast Breeding Zone in the fall of 2001 at the age of 14 years. These data will remain on file pending a decision on the direction of the program in this zone.

In the Lake Winnipeg East Breeding Zone, weevil control, using Methoxychlor, was conducted at the Currie Landing family test in 2000, 2001, and 2002. The first crown management and a secondary selective roguing for spacing were completed at the Brightstone seed orchard in the fall of 2000. These were timed to coincide with the first cone collection which produced 0.6 kg of seed. A second cone collection was conducted in 2001 producing 1.06 kg of seed. These projects were completed in co-operation with Tembec Forest Resources.

In the Interlake Breeding Zone, the Mantagao mass selection seed orchard was rogued (bottom 25%) in 2000 based on height measurements that were completed in the spring of 1999. The second height measurements at the Lake St. George mass selection seed orchard were completed in the spring of 2002. These will be used, along with visual comparison, to rogue the orchard for the second time.

In the Mountain Breeding Zone, three family tests (18 750 trees) and a seed orchard (10 710 trees) were established in the spring of 2001 in co-operation with LP Canada Ltd.

In the Saskatchewan River Breeding Zone, weevil control, using Methoxychlor, was conducted at the Root Lake and Simonhouse family tests in the spring of 2001 and 2002. The first partial roguing of the Prospector seed orchard was completed in 2000 removing the bottom 25% ranked families. The first cone collection at Prospector was done in the fall of 2001 producing 0.32 kg of seed.

In the Highrock and Nelson River Breeding Zones, on-going maintenance was conducted.

WHITE SPRUCE

In the Mountain Breeding Zone, weevil control using Methoxychlor was conducted at the Boggy Creek and Rice Creek family tests in 2000 and 2001. The Shortdale family test was also sprayed in 2001. The second crown management was conducted at the Birds Hill clonal seed orchard in the fall of 2000. Cone induction, using gibberellin injections and some root pruning, was carried out in the original section of the orchard (planted in 1994) in 2001 and 2002. The first significant cone crop will be collected in the fall of 2002. Cone crop monitoring will determine the success of the cone induction treatments and clonal balance. LP Canada co-operated in these projects.

In the Saskatchewan River Breeding Zone, the first crown management at the Reader Lake clonal seed orchard was done by Tolko in the spring of 2002. Polycross pollen donors have been selected from throughout the Breeding Zone. Polycross breeding for progeny tests will be initiated pending a cost sharing agreement with Tolko Manitoba.

BLACK SPRUCE GENETIC DIVERSITY

Dr. Om Rajora completed a study of genetic diversity in black spruce in two ecoregions in Manitoba. The study found that there are typically moderate to high levels of genetic diversity within the sampled black spruce populations. It also concluded that harvesting and forest regeneration practices, currently used in the province, do not appear to have reduced the levels of genetic diversity. The data from this study will be used as benchmarks to monitor the level of genetic diversity of future forests to ensure that the black spruce genetic resource of the province continues to be managed in a sustainable manner. This project was jointly funded by the Manitoba Forestry Branch, Tolko Manitoba, Tembec Forest Resources, LP Canada, and the Manitoba Model Forest.

AAC ADJUSTMENTS FOR IMPROVED SEED

The Manitoba Forestry Branch is currently investigating methods to determine levels of genetic gain obtained from improved seed and how to incorporate the benefits into annual allowable cut determinations.

HYBRID POPLAR CLONAL TRANSECT ESTABLISHMENT

The Tree Improvement section is assisting the Canadian Forest Service in the establishment of six sites in Manitoba as part of the prairie-wide test of twelve hybrid poplar clones. A demonstration plot was also established near the tree improvement headquarters and another site is testing white spruce understory in conjunction with hybrid poplar.

WEYERHAEUSER – TREE IMPROVEMENT IN SASKATCHEWAN

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Keywords: seed orchard, provenance trial, cross-pollinating, top grafting

JACK PINE PROGRAM

A first generation grafted orchard is exceeding all operational seed requirements. A small local market for improved jack pine seed has emerged over the last three years. Seed sales, along with reduced cone collections, have allowed us to improve the management of our seed inventories.

Cross-pollinating in ten of twelve sublines for the next generation is progressing well. A protocol for "top-grafting" onto the crown of established orchard and breeding bank trees has been successfully developed and has allowed us to relocate a significant portion of our breeding work to the Orchard property. In 2001 the first of a series of full-sib trials to be established was sown and planted on four sites in the spring of 2002. Seed was acquired from two partial sublines. Two more partial sublines were sown in the greenhouse in spring 2002 for planting in 2003.

WHITE SPRUCE PROGRAM

A first generation grafted orchard is now meeting all operational seed requirements.

Data collected and analyzed from 12 white spruce Neldar trials established in 1976 by the Provincial Government across the white spruce range in Saskatchewan are being used to negotiate with the Province to allow for the deployment of orchard seed onto our Pasquia Porcupine FMA. The data analysis was completed by Dr. Dudley Huber, University of Florida and indicated no GxE across the 12 sites.

BLACK SPRUCE PROGRAM

We are presently investigating the possibility of incorporating a black spruce program to provide a reliable and consistent supply of seed for operational use. The size and intensity of the program has yet to be determined. In the meantime, black spruce seed is collected from wild stands.

PFRA SHELTERBELT CENTRE – TREE IMPROVEMENT SUMMARY

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Keywords: shelterbelt, agroforestry, tree improvement, *ex situ* conservation

Agroforestry planting has been carried out in the Canadian Prairies for over 100 years. The major problem facing prairie tree planters is having trees that survive and perform adequately on sites where they do not naturally occur. The PFRA Shelterbelt Centre has, over the past 80 years, concentrated on introducing and improving tree species for the prairies. The objective of the program is to develop trees that are able to survive and are functional agroforestry plantings under the inhospitable conditions characteristic of the Canadian Prairies. Because of the commitment to developing genetically diverse tree plantings, improvement programs have concentrated on developing superior seed-propagated populations of Scots pine (*Pinus sylvestris* L.), Siberian larch (*Larix sibirica* Ledeb.), green ash (*Fraxinus pennsylvanica* Marsh. var. *subintegerrima* (Vahl.) Fern.), sea buckthorn (*Hippophae rhamnoides* L.), and bur oak (*Quercus macrocarpa* Michx.) and improved clonally propagated poplar hybrids (*Populus* spp.). The Centre also maintains germplasm libraries of prairie woody plant genera. Improved trees and shrubs developed in the program are used for farm, field and roadside shelterbelts, wildlife habitat planting, riparian buffers, and afforestation.

SIBERIAN LARCH

Improvement of Siberian larch has been under way since 1981. The objective of the larch program is to develop genetically improved plants for agroforestry planting in the prairies. From 1985 to 1995 Siberian larch seed was obtained form numerous Siberian sources. These sources have been planted in test locations throughout the province of Saskatchewan (Table 1).

Table 1. Siberian larch improvement field trials

Test Location	Accessions in Test	Year Planted
Canora, SK	7	1985
Indian Head, SK	11	1985
Indian Head, SK	10	1985
Indian Head, SK	12	1987
Indian Head , SK	10	1991
Birch Hills, SK	60	1993
Fort Qu'Appelle, SK	26	1995
Meadow Lake, SK	29	1995

GREEN ASH

Improvement of green ash has been under way since 1985. The objective of the green ash program is to develop genetically improved seed sources for agroforestry planting in the prairies. From 1982 to 1987 green ash seed was collected from superior trees in it's native range in the northern Great Plains of United States and the Canadian Prairies. These sources were planted in test locations throughout the province of Saskatchewan and in Manitoba (Table 2).

Table 2. Green ash improvement field trials

Test Location	Accessions in Test	Year Planted
Indian Head, SK	61	1987
Birch Hills, Indian Head, SK	30	1989
Brandon, MB	20	1993
Weyburn, Ruddell, Zelandia, SK	23	1994
Indian Head, Maple Creek, SK	26	1997

POPLAR

The poplar improvement program at the Shelterbelt Centre is a major activity. Poplars are used for shelterbelts, riparian buffer systems, phyto-remediation, and afforestation. The Centre maintains an extensive clonal library. A breeding arboretum was established in 1988 to provide flower branches for controlled breeding. The arboretum includes 50 clones and is being expanded annually. Clonal testing of poplars has been conducted by the Shelterbelt Centre for over 50 years.

Breeding Program

In 2001, a five year hybrid poplar breeding project was initiated. The project focuses on development of hardy, fast growing, drought and pest resistant hybrid poplar for afforestation and agroforestry.The breeding project is being conducted in partnership with Alberta Pacific Forest Industries. The objective of the program is to enlarge the genetic basis of poplar to face biotic and abiotic constraints in order to select new clones with strong adaptation to harsh conditions and high yield. There is controlled crossing to produce inter-specific hybrids of selected *P. deltoides*, *P. balsamifera*, *P. maximowiczii*, *P. nigra* and *P.x petrowskyana* and identifying superior *Populus* genotypes by conducting nursery evaluations of control-pollinated seed lots and field scale testing.

The breeding project concentrates on producing interspecific hybrid seed lots. First filial (F1) generation hybrid combinations are being attempted using *Populus deltoides*, *Populus deltoides* x *Populus x petrowskyana* and *Populus balsamifera* female clones. Pollen sources include native *Populus deltoides* from Alberta and Saskatchewan, *Populus nigra* from northern China, *Populus maximowiczii* from Québec, and native *Populus balsamifera* from Alberta.

Selection of breeding materials is based on availability of flowering material, existing growth data, and insect and disease resistance ratings from existing test plantations. The breeding program goal in 2001 and 2002 was to attempt 150 crossing combinations. The primary attention of the breeding program is aimed at producing new F1 interspecific hybrid seed lots, specifically: *P. deltoides* x *P. balsamifera* (and its reciprocal, *P. deltoides* x *P. nigra*, *P. deltoides* x *P. maximowiczii*, *P. deltoides* x *P. petrowskyana*, *P. balsamifera* x *P. maximowiczii*, *P. balsamifera* x *P. nigra*, (*P. deltoides* x *P. petrowskyana*) x *P. nigra*, (*P. deltoides* x *P. petrowskyana*) x *P. maximowiczii*, and (*P. deltoides* x *P. petrowskyana*) x *P. petrowskyana*.

Clone Tests

Clonal testing of poplar has been a major activity at the Centre since the 1960's. From 2000–2002 ten clonal tests were established in the prairie region (Table 3). Clone tests were established in cooperation with the forest industry and private landowners. The objective of these tests was to evaluate performance of clones in afforestation and agroforestry applications.

Table 3. Poplar clone tests established 2000–2002

Test Location	Clones per Test	Year Planted
Boyle, AB	53	2000
Prince Albert, SK	39	2000
Pleasantdale, SK	43	2001
Boyle, AB	10	2001
Manning, AB	37	2001
Grand Prairie, AB	25	2001
Arborfield, Star City, Meadow Lake, Makwa, SK	50	2002

SEED ORCHARD

The 10 ha seed orchard was established in 1987 with the planting of Siberian larch and green ash. In 1990, the Scots pine orchard was established. The orchard provides improved seed for the nursery production program at the PFRA Shelterbelt Centre.

EX SITU CONSERVATION OF WOODY PLANTS

The Centre is involved in evaluation and conservation of woody genetic resources in the prairie region. This includes sampling native woody plant populations and establishment of *ex situ* conservation nurseries. Collections are under way or have been completed for choke cherry (*Prunus virginiana* (A.Nels.) Sarg.), round leaf hawthorn (*Cretaegus rotundifolia* Moench.), buffaloberry (*Shepherdia argentea* Nutt.), western snowberry (*Symphoricarpos occidentalis* Hook.), Wood's rose (*Rosa woodsii* Lindl.), bur oak (*Quercus macrocarpa* Michx.), green ash (*Fraxinus pennsylvanica* Marsh. var *subintegerrima* (Vahl.) Fern.), plains cottonwood (*Populus deltoides* Marsh. var *occidentalis* Rydb.), Canada plum (*Prunus nigra* Ait.), and American plum (*Prunus americana* Marsh.).

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GENETICS, TREE IMPROVEMENT, EVOLUTION AND CONSERVATION RESEARCH AT THE UNIVERSITY OF ALBERTA

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Keywords: quantitative and population genetics, conservation, early selection, tree improvement, balancing gain and diversity, introgression, genomic mapping, QTL and gene expression

During the past two years we have achieved the following accomplishments: 1) doctoral student Deogratias Rweyongeza completed his degree based on a retrospective early genetic evaluation and selection in white spruce (*Picea glauca* [Moench] Voss) using seedling traits and seasonal growth curves; 2) doctoral student Jonathan Cornelius investigated the mating system and the genetic effects of forest fragmentation in Costa Rica; 3) doctoral student Terrance Ye studied the coevolution of western gall rust (WGR) with lodgepole pine (*Pinus contorta* Dougl.) and jack pine (*P. banksiana* Lamb) hosts; 4) doctoral student Aron Fazekas investigated the genetic structure and speciation of lodgepole pine using RAPDs and sequencing data; 5) doctoral student Safiah Atan worked on genetic linkage and QTL mapping of *Hevea* latex-timber clones; and 6) MSc student Rose Guardamano worked on somatic embryogenesis and gene expression in jack pine and black spruce (*Picea mariana* [Mill] BSP).

We collaborated with the Alberta Land and Forest Service on the genetics and breeding of lodgepole pine and white spruce. Geographic variation patterns, heritabilities and genetic correlations, genetic gain predictions, geographic variation and host-fungus interaction in WGR incidence, retrospective early testing and selection, deployment of genotypes to balance genetic gain and diversity, and QTL mapping for resistance to WGR have been major components of our studies.

A considerable amount of effort and time was spent to support POPGENE, the Microsoft Windows–based user-friendly freeware for population genetic analysis. POPGENE started as a joint project between the University of Alberta and Center for International Forestry Research. The current version (POPGENE 1.32) is distributed on the World Wide Web http://www.ualberta.ca/~fyeh/ .

ACKNOWLEDGMENTS

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GENETICS AND TREE IMPROVEMENT PROGRAM, 2000-2002
ALBERTA SUSTAINABLE RESOURCE DEVELOPMENT

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Keywords: tree breeding, provenance studies, species testing, seed orchards, clone banks, progeny testing, selection, climate change

This report summarizes the progress of the Land and Forest Division (LFD) genetics and tree improvement program for the period 2000–2002. A large part of the work was done in collaboration with forest industry, Alberta Agriculture and Rural Development, University of Alberta, North Peace Applied Research Association, Canadian Forest Service, U.S. Forest Service, and BC Ministry of Forests.

PROGRAM DEVELOPMENT

The Alberta Forest Genetics Framework (AFGF) process was started as a cooperative effort between the government and industry. AFGF is a comprehensive exercise to develop an integrated group of policies and standards to guide management and conservation of forest genetic resources in Alberta. The work is nearing completion and implementation is scheduled for early 2003. The Alberta Forest Genetic Resources Council continued its work. Noteworthy topics and issues addressed were: reforestation with non-native tree species, genetically modified organisms (GMOs), a provincial genetic resources conservation plan, and a genetic resources benchmarking program for Alberta.

GENETIC IMPROVEMENT

Assembly of Breeding Stock

Geographic and superior parent tree selections were made as part of LFD/Industry cooperative breeding projects included 164 white spruce (*Picea glauca* [Moench] Voss), 22 black spruce (*Picea mariana* [Mill.] BSP), 5 lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), and 51 white spruce/Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) hybrids.

Companies participating in these projects include ANC Timber Ltd., Blue Ridge Lumber (1981) Ltd., Canadian Forest Products Ltd. (Grande Prairie Division), Manning Diversified Forest Products Ltd., Millar Western Forest Products Ltd. (Whitecourt), Northlands Forest Products Ltd., Sunpine Forest Products Ltd., Tolko Industries Ltd. (High Level Lumber Division), Weldwood of Canada Ltd. (Hinton Division), and Weyerhaeuser Canada Ltd. (Grande Prairie and Drayton Valley Divisions).

Sixty single-tree white spruce cone collections were made in Cypress Hills Provincial Park for a proposed series of progeny trials to be established in central Alberta. Higher elevation portions of this park are of interest as they were not glaciated during the last glacial advance and now support 'outlier' island populations of white spruce that are considered to be unique and show promise for selection and breeding for climate change adaptation in northern Alberta.

Genetic Testing

Progeny trials for lodgepole pine Breeding Region J (Clear Hills) commenced in 2000. Three trials were established in a randomized complete block design. Ninety-seven families were represented including 25 from Breeding Region J, 43 from the adjacent foothills region in British Columbia (BC) and 29 from other Alberta lodgepole pine breeding regions and the Saddle Hills.

White spruce provenance and family tests of BC, Québec, and Alberta materials were established in a randomized complete block design on two sites in 2001. The trials include 25 British Columbia families from the Central Plateau and Hudson Hope regions, the top 20 families in the Québec white spruce breeding population, and 11 Alberta families from Breeding Regions D1 (boreal mixed wood) and G1 (northern foothills and Saddle Hills).

Four small Scots pine (*Pinus sylvestris* L.) field evaluation trials were established in 2000 and 2001 at the Crop Diversification Centre at Brooks and at the Alberta Tree Improvement and Seed Centre (ATISC). The trial series was commenced in 1998 to examine the seasonal stability and uniformity of the materials for crown shape and needle colour for amenity tree attributes. Test materials consist of seedlings from open-pollinated bulk and single clone collection seed lots from a clonal seed orchard established at ATISC with selections made from a seed source trial located in Russia.

In 2002, progeny trials for white spruce Breeding Region G2 (Peace Region) were established on three sites using an alpha design. A total of 124 families is in the tests including 63 from Region G2, 37 from the interior spruce program in British Columbia and 24 from adjacent white spruce breeding regions and associated progeny trials.

Sixteen-year assessment of a white spruce progeny trial for Breeding Region G1 was completed in 2000. Survival, plant vigor, height, leader growth, and white pine weevil incidence were measured or assessed. Heritabilities for 16-year height were 0.18 (individual) and 0.33 (family). Genetic correlation between 11- and 16-year height was 0.96. Mean weevil attack incidence was 9% and family differences in weevil attack incidence were not significant.

Height and survival of lodgepole pine Breeding Region K (Southern Foothills) progeny tests were assessed in 2001 at 6 years from seed. For the Clearwater site, six-year survival was 89.3% (progenies ranged from 70 to 100%) with an average plantation height of 104.8 cm (progeny range of 84.4 to 132.2 cm). Six-year survival on the Dry Creek site was 87.7% (progeny range of 66.7 to 100%) with an average plantation height of 117.6 cm (progeny range of 81.5 to 147.7 cm).

Seed Orchards and Clone Banks

To date, geographic selection of 42 parents has been completed for a black spruce seed production project for Breeding Region L3 (Northeast Boreal Mixedwood). Cooperators in the project are Northland Forest Products Ltd. and LFD. Graft production is ongoing for a 400 ramet orchard established in 2001.

A cooperative white spruce tree improvement project for Breeding Region E1 (Northeast Boreal Mixedwood) between Northlands Forest Products Ltd. and LFD is well underway and is being considered for expansion to accommodate needs of the regional Oilsands industry. Sixty-seven parent trees have been selected and graft production is on-going. Initial planting of a 510 ramet orchard began in 2000.

All parent tree selections are completed for a cooperative jack pine (*Pinus banksiana* Lamb.) tree improvement project for Breeding Region P1 (Northeast Boreal Mixedwood) involving Northland Forest Products Ltd. and LFD. Graft production of 59 parents is on-going and establishment of a 561-ramet orchard at Wandering River began in 2000. Grafts of these parent trees are maintained in a jack pine clone bank established at ATISC in 2000.

Establishment of the Breeding Region G2 (Peace region) white spruce clonal orchard is well underway at North Star, south of Manning. The 104-clone, 800-ramet orchard is about 70% filled. Manning Diversified Forest Products, Tolko Industries Ltd. (High Level Division), and LFD are the current partners in this project. North Peace Applied Research Association (NPARA) assists in the establishment and maintenance of the orchard.

The Breeding Region J (Peace region) lodgepole pine clonal orchard, also located at the North Star site, was expanded from 400 to 620 ramets when Tolko Industries Ltd. (High Level Division) joined the project. Over the next three years, 15 additional parent tree selections will be made in the northern area of the breeding region as part of the expansion. Manning Diversified Forest Products Ltd. is also a major partner in this project. NPARA provides assistance in orchard establishment and maintenance.

Cone and Seed Insects

A study to monitor spruce seed moth (*Cydia strobilella*) using synthetic pheromone baits in sticky traps was concluded in 2000. The study was conducted for four consecutive years and trapping was done in three white spruce seed orchards located at ATISC.

The pheromone baited traps proved to be a reliable and efficient method of detecting populations of the seed moth and provided reliable year-to-year trends in population levels. However, annual capture data did not correlate well with percentage of cones infested and, consequently, predictions of seed loss leading to timely control measures could not be formulated.

The study showed that tree and stand development characteristics specific to each orchard contributed to variation between orchards in moth population levels. Differences in tree age and crown size, presence and abundance of conelets, topographical features, and nearness to surviving populations occurring in adjacent natural stands of white and black spruce are likely the most significant factors.

The relative size of cone crops can serve as an indicator of the expected infestation level of the seed moth; infestation levels were highest in years of low cone production and, conversely, were lowest in the year of high cone production. The low infestation level apparently results from a dilution of the available seed moth population.

GENETICS AND TREE IMPROVEMENT RESEARCH

Provenance Studies

Twenty-four year assessments were completed on five trials in the Alberta-wide white spruce provenance series. This series includes 13 trials established throughout Alberta. Twenty-seven seed sources were evaluated for survival, total height, and DBH. A Canada range-wide white spruce provenance trial was also evaluated at 24 years. The trial includes 43 white spruce seed sources from across Canada.

Two expanded Canada range-wide white spruce provenance trials were assessed at ten years from seed. Forty white spruce seed lots from across Canada are represented. The trials were assessed for survival and total height.

Survival and total height were also assessed in a series of four white spruce provenance trials at ten years from seed. The trials consist of a total of ten seed lots from Québec, Ontario, and Manitoba and 13 Alberta seed lots representing the range of white spruce in the province.

Three tamarack (*Larix laricina* [Du Roi] K.Koch) and seven black spruce provenance trials were assessed at 15 years from seed. The tamarack trial series is comprised of 18 tamarack and two Siberian larch (*Larix sibirica* Ledeb.) seed lots. Twenty seed lots are included in the black spruce trial series. Survival, total height, and DBH were assessed.

Fifteen-year assessments were completed on two lodgepole pine, jack pine 'outlier', and hybrid population trials. Survival, total height, and DBH were assessed. This series of ten trials consists of 37 seed lots from Alberta and BC.

A Siberian larch seed source trial was assessed at 11 years from seed. The trial consists of seven Siberian larch seed lots from Russia; a Siberian larch seed lot from Indian Head, Saskatchewan (original provenance unknown), a Raivola larch (*Larix sibirica* var. *raivola*) seed lot, and a *Larix gmelinii* (Rupr.) Kuzen. seed lot from China. Survival, total height, DBH, stem form, and crown density were assessed.

Two United States/Canada Engelmann spruce provenance trials were assessed at two and four years from seed. The trials include seed lots of phenotypically superior Engelmann, hybrid, and white spruce. The four-year-old trial contains a total of 51 seed lots: 42 from Idaho and Montana, two from interior BC, and seven from Alberta. Survival and total height were assessed. A total of 73 seedlots are included in the two-year-old trial: 44 from BC, 20 from Alberta, and nine from Idaho and Montana. Only survival was assessed.

In 2000, four Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) provenance trials for the southern foothills were assessed at 10 years from seed for height and survival. Sites and provenances as well as their interaction were significant for both survival and height. Survival for sites ranged from 21.0 to 92.6% while for provenances, the range across sites, varied from 56.1 (Jasper source) to 85.6% (Highwood source). Site differences for mean height ranged from 18.9 to 228.3 cm. Provenance mean heights across sites ranged from 89.8 (Highwood source) to 110.4 cm (Porcupine Hills source). The strong negative correlation (r=-0.88) between percent survival and mean provenance height at five years, weakened by year 10 as slower growing southern sources with better survival and plant health scores at the 5-year assessment started overtaking initially faster growing but less hardy northern sources at year ten.

Climate Change and Genetic Variation of Forest Tree Species Populations

The development of an Alberta Climate Prediction Model (ACPM) and the associated GIS products is nearly complete and the work is in progress to incorporate climate change scenarios for future climates (2030, 2060, and 2090) using the Canadian General Circulation Model. Field provenance trial measurement data sets are being organised to develop response and climate transfer functions to evaluate growth and survival responses of species and seed sources to predicted climate change.

Flowering and Cone Induction Studies

In previous studies, abundant female flowering was achieved on potted white and black spruce grafts using $GA_{4/7}$ and heat treatment, but cone size and seed yield were considerably below average to that produced in soil based white spruce orchards. The relationship between root vigor and cone development and seed yield was investigated using three different potting methods. All grafts in the study were injected with $GA_{4/7}$ and were subjected to a 3-week heat treatment. Cone length and width, 1000-seed weight, and number of seeds per cone were positively correlated with larger root volumes.

GENETIC RESOURCES CONSERVATION

Provincial Conservation Plan

One of the initiatives of the Alberta Forest Genetic Resources Council, formed in April of 2000, was the development of a plan for conserving the genetic resources of forest trees. The adopted plan identifies gap analysis, implementation steps, and reporting as three main areas of endeavour. Most of the initial work has been directed at gap analysis tasks including determination of species for conservation, their natural distribution, and status and information needs. Efforts are to be collaborative and, to date, planning involves participation of LFD, forest companies, and Alberta Parks and Protected Areas (APPA).

Conservation Activities

Conservation work, while awaiting development and implementation of a provincial plan, has involved routine clone banking and seed archiving for parent tree selections being made as part of tree improvement programs. In addition, special seed collections have been made for several under-represented species such as alpine fir (*Abies lasiocarpa* [Hook.] Nutt.) and Douglas-fir, and for species from several under represented areas such as jack pine from the Canadian Shield Natural Region, white spruce and lodgepole pine from the Cypress Hills Region in south eastern Alberta, and high elevation spruce and alpine fir from the Porcupine Hills Region. A special collection is also under way for limber pine (*Pinus flexilis* James) which has been put on the provincial watch list due to its limited distribution and increasing attack by white pine blister rust (*Cronartium ribicola*).

Recognising the inter-disciplinary and inter-agency nature of conservation efforts, LFD has developed a cooperative agreement, in conservation efforts, with APPA as well as forest companies. Areas of cooperation with APPA include identification of species for conservation, determination of status and priorities by species, information sharing and mapping of species distributions and abundance, working on establishment and management of an *in situ* forest gene conservation reserve network, making special *ex situ* collections, and targeted research.

PLANT PROPAGATION, WOOD, SEED AND POLLEN TECHNOLOGY

Plant Propagation

During the report period, stock production consisted of approximately 12 500 seedlings for rootstock and 50 000 seedlings for experimental trials. In addition 30 000 seedlings were produced for the conservation trees production program which includes give away trees for National Forestry Week, Arbour Day, ceremonial needs, community plantings, and habitat restoration. One thousand seedlings were produced for shelterbelt stock and 3 000 seedlings for a parks and protected areas planting in the Cypress Hills. Graft production consisted of 3 500 grafts.

Wood Technology

During the report period, specific gravity and fibre length measurements were completed on 211 parent trees. Of these, 138 were white spruce, 5 were lodgepole pine, 35 were black spruce, 20 were alpine fir, and 13 were Douglas-fir.

Seed and Pollen Technology

Over the report period, 378 seed lots were added to the genetics seed bank. The majority of entries were white spruce (99), black spruce (69), balsam poplar (*Populus balsamifera* L.) (16), Scots pine (18), and lodgepole pine (6). Other species added to the seed bank include alpine fir (20), Douglas-fir (21), tamarack (6), and limber pine (6). To date the seed bank contains 4 874 seedlots.

Reference seed lots representing 2% of the seed bank entries have been monitored for 21 years. Lodgepole pine seed lots have remained stable with a mean germination of 87% in 1981 and 87% in 2001. White spruce seed lots have declined slightly from a mean germination of 91% in 1981 to 86% in 2002. Mean germination of aspen (*Populus tremuloides* Michx.), plains cottonwood *(Populus deltoides* Bartr.), and balsam poplar have declined 11–33% after 11 years of testing.

Thirty-five clonal white spruce pollen collections were completed and viability tests (electrical conductivity and germination) were completed on 19 of the pollen lots. Controlled pollinations using two bulk white spruce pollen lots were completed on 14 grafts in the white spruce clone bank at ATISC to relate *in vitro* test results to actual field fertility. Laboratory trials were conducted to determine the change in percent electrical conductivity of pollen with leaching time and to determine the effect of time in a dessicator and at ambient laboratory conditions on pollen moisture content.

REFORESTATION SEED PROGRAM

The Reforestation Seed Program is responsible for the registration, storage, distribution, and tracking of tree seed used for public land reforestation. At the end of the report period, there were 18 tree species represented in seed storage by 1 570 individual lots for a total of 41 000 kilograms of seed. During the reporting period, 2 340 kilograms of seed were withdrawn for seedling production, direct seeding, testing, and research projects and 206 new seedlots were collected and registered.

As part of the Alberta Forest Genetics Framework discussions, a technical task group completed work on the “Materials Collection, Handling, Registration and Storage Policy” which covers regulations that deal with collection, processing, testing, registration, storage, withdrawal, and transportation of tree seed for public land use. Work on seed zones development for Alberta is nearing completion. Ecological natural subregions are being used as the basis for seed zones delineation. The province is divided into a total of 84 seed zones.

ISABELLA POINT FORESTRY LTD.: ACTIVITIES 2000 – 2002

S.E.T. John and J.S. Brouard

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Keywords: seed orchard, progeny, provenance, experimental design, policy

Isabella Point Forestry Ltd. is a small consulting firm providing technical expertise in forest genetics. During the period 2000–2002 we have focused on a range of activities in Alberta and British Columbia (BC). These include: program planning and implementation for tree improvement programs in Alberta, development of forest genetics policy for Alberta, seed supply analysis and forecasting in BC, and investigation of the interaction of silviculture and disease with genetics in BC.

ALBERTA

Policy Development

The Alberta Forest Genetics Framework (AFGF), set up by the Department of Sustainable Resource Development, Alberta Land & Forest Division in the second half of 2001, has recently completed a comprehensive draft policy governing management and conservation of Alberta's forest genetic resources. SJ (S. John), appointed to this body on behalf of a consortium of Alberta forest companies, focused particularly on technical standards regarding diversity levels in improved planting stock and relatedness across generations of improved stock. JB (J. Brouard) provided a background paper assessing ownership and access rights for genetic resources in other jurisdictions, nationally and globally, to the AFGF. SJ has represented a group of forest companies as councillor on the Alberta Forest Genetic Resources Council since its inception in April 2000.

Program Planning and Implementation

Working with individual companies and industrial cooperatives, we provide technical direction for tree improvement programs in lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.), white spruce (*Picea glauca* [Moench] Voss), black spruce (*Picea mariana* [Mill.] B.S.P.), trembling aspen (*Populus tremuloides* Michx.), and hybrid poplar (*Populus* spp.). Our role includes preparation and updating of detailed breeding and work plans, orchard design, test design, layout and analysis, and seed orchard operational research on topics such as flower stimulation, phenology, selfing, and crown management. More than 30 genetic tests, involving approximately 100 000 test trees, have been designed by us and established by cooperators during this period. We focus particularly on sound strategy development, ensuring a broad and appropriate program genetic base, and error control through appropriate trial design and layout.

BRITISH COLUMBIA

Seed Orchard Planning

Working with BC Ministry of Forests (MoF) and industry staff, JB continues to provide seed supply planning, analysis, and forecasting services for the BC Forest Genetics Council, Forest Renewal BC, and SelectSeed Ltd. Results are used to prioritize investment opportunities in operational tree improvement and improve seed orchard planning in BC.

Certification

For the Tree Improvement Branch, MoF, JB completed a review of BC's tree seed management system, addressing certification-related concerns and issues.

Cross-disciplinary Research

A small project, implemented through the Morice and Lakes Innovative Forest Practices Agreement (IFPA), considers some possible interactions of genetics with silviculture and disease.

Does Genotypic Rank Depend on Inter-tree Spacing? This component investigates the interaction between tree espacement and genotype as it affects growth performance. If ranking of genotypes in genetics trials was found to depend on inter-tree spacing, this could influence optimal trial design. A trial involving six families of contrasting crown architecture was established in 2001 near Burns Lake, BC, using a Marynen (or plaid) factorial design, with inter-tree spacing ranging from 0.6 to 2.4 m. Preliminary results are expected by 2006.

Does Resistance to Comandra Rust Have a Genetic Basis? In 2000, we assessed a 14–15-year-old lodgepole pine MoF progeny test site for comandra rust (*Cronartium comandrae* Peck.) infection. Analyses by SJ demonstrated that variation in susceptibility to this rust has a highly significant genetic basis and found that infection rates by family ranged from 0 to 69% in the study population.

Is Resistance Provenance-based? Regression analyses conducted by SJ in 2001-02 revealed that latitude, longitude, and elevation did not explain variation in resistance. However, cluster analysis succeeded in partitioning the study population into nine geographical groups in such a way that 32% of the variation in infection is attributable to the grouping. Data and results from this study have been used by MoF genetics staff to identify several provenances resistant to comandra rust.

Clonal Competition in Yellow-cedar JB designed and assisted with implementation of a farm-field clonal competition dosage study in yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) for the MoF, Research Branch.

FOREST GENETICS AT THE FACULTY OF FORESTRY, THE UNIVERSITY OF BRITISH COLUMBIA, 2000–2002

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GENE CONSERVATION AND ADAPTATION
S.N. Aitken

The research of my lab group and collaborators currently emphasizes gene conservation, but still include genecology and the genetics of adaptation to stress. We established the Centre for Forest Gene Conservation (CFGC) (http://genetics.forestry.ubc.ca/cfgc) in 2000, with support from the Forest Genetics Council of BC. A. Hamann has been leading a project in collaboration with A. Yanchuk and others at the BC Ministry of Forests (MoF) to catalogue current *in situ* conservation of genetic diversity for tree and shrub species in BC using a GIS approach. *Pinus albicaulis* Engelm., whitebark pine, is a species at risk due to white pine blister rust, fire exclusion, and climate change. J. Krakowski completed a MSc project that found that whitebark pine has a mixed mating system with a bimodal distribution of outcrossing rates and geographic trends in levels of inbreeding in mature trees. PhD student A. Bower (UBC) has initiated a follow-up project on adaptive variation, inbreeding, and major gene resistance to white pine blister rust in whitebark pine. W. Gapare, (PhD candidate, UBC), is assessing sampling strategies for capturing allelic diversity in *ex situ* conservation collections at different spatial scales using Sitka spruce (*Picea sitchensis* (Bong.) Carr.) as a model species. Sitka spruce is also being used as a model species in a project investigating the effects of gene flow on adaptation in widespread conifers in the PhD research of M. Mimura (UBC). I am also collaborating with B. Fady and others (INRA, Avignon, France) on a project investigating levels of genetic variation for core and marginal populations of *Abies alba* Mill. in western Europe for genetic markers and adaptive traits. We continue to investigate the quantitative genetics of adaptive traits in conifers in tree improvement programs. T. Wang (UBC), in collaboration with K. Kavanagh (University of Idaho), has determined that simultaneous selection for growth and wood density in lodgepole pine (*Pinus contorta* Dougl.) may affect hydraulic architecture and vulnerability to cavitation. He also found geographic clines in vulnerability to cavitation in Douglas-fir in the transition between coastal and continental climates in BC. G. O'Neill (UBC, MoF), in collaboration with R. Alfaro of Canadian Forest Service (CFS) and J. King (MoF), found strong genetic clines in resin canal defenses related to resistance to the weevil (*Pissodes strobi* Peck.) in the introgression zone between Sitka and white spruce (*Picea glauca* [Moench] Voss.). These clines correspond with the molecular hybrid index estimates of PhD candidate S.Y. Bennuah (UBC) based on nuclear STS markers. The impacts of low and moderate levels of inbreeding in advanced generation seed orchards of coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) on final stand yields were found to be small to negligible in simulations conducted by T. Wang (UBC) in collaboration with J. Woods (SelectSeed Co.), K. Mitchell and K. Polsson (MoF), and S. Magnussen (CFS).

ALTERNATIVE SILVICULTURAL SYSTEMS, MINOR TREE SPECIES, SEED BIOLOGY, GENE CONSERVATION, INTEGRATED PEST MANAGEMENT, ECOPHYSIOLOGY, AND SOMATIC EMBRYOGENESIS
Y.A. El-Kassaby

Several research projects are being conducted in collaboration with my students, research associates, and colleagues. They cover very diverse topics that are all relevant to the development of successful forest management and conservation strategies. These are: 1) evaluation of modern harvesting systems on the genetic diversity and genetic quality of natural regeneration. In collaboration with B.G. Dunsworth (Weyerhaeuser Inc.) and J. Krakowski (UBC), the Montane Alternative Silviculture Systems (MASS) Project provided the research material for this study and several harvesting methods with replicated treatments representing a range of overstory removal, namely, shelterwood, patch clearcut, and green tree retention were evaluated and compared to adjacent old-growth and clearcut 'control' areas. Two species are being investigated (western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and balsam fir (*Abies balsamea* [L.] Mill.)). 2) The genetic diversity of three minor tree species (whitebark pine, Garry oak (*Quercus garryana* Dougl.) and arbutus (*Arbutus menziesii* Pursh)) are under investigation for the purpose of developing sound conservation strategies. These are being conducted in collaboration with M. Meagher and G. Edwards (formerly CFS) and

S. Aitken, J. Beland, J. Krakowski, and K. Ritland (UBC). 3) The effects of seed pre-treatment and simulated aging on germination of Douglas-fir, white spruce, western hemlock, and lodgepole pine are being investigated to determine the extent of genetic control over germination attributes and its impact on seedling production as well as to evaluate the efficacy of the use of seed storage as an *ex-vitro* gene conservation method with A. Benowicz and J. Krakowski (UBC), and G. Edwards (CFS). 4) Two studies relevant to **I**ntegrated **P**est **M**anagement are underway by graduate students. C. Liewlaksaneeyanawin has successfully completed his MSc thesis on genetics of the white pine weevil (= spruce weevil) *Pissodes strobi* (Peck) and J. Wilkin is investigating the genetics of the salal-valdensinia; a host-parasite system for the purpose of the development of an effective biological control system. These studies are being conducted in collaboration with R. Alfaro and S. Shamoun (CFS) and C. Ritland and K. Ritland (UBC). 5) The propagation of yellow-cedar (*Chamaecyparis nootkatensis* [D. Don] Spach)is being evaluated using cuttings, from 3, 7, 11, and 15-year-old donor hedges with A. Benowicz and J. Krakowski (UBC). Cuttings were produced from serially-propagated hedges as well as from hedges of the same age that were not serially-propagated. Several growth (size and form) and ecophysiological (photosynthesis and cold-hardiness) attributes are being evaluated to determine the effect of age and source on cutting quality for the purpose of developing effective propagation methods. The research material for this project was kindly provided by J. Russell (MoF). 6) Several projects related to the use of somatic embryogenesis (SE) as a method for bulking-up elite genotypes are underway with A. Benowicz, J. Krakowski, and I. Moss (UBC) These include its use as a propagation method for Sitka spruce resistant to weevil, its economic evaluation, and comparison between SE and zygotic seedlings for Douglas-fir and Sitka spruce.

POPULATION GENETICS AND GENOMICS

K. Ritland

The research conducted in my lab spans conservation genetics, population genetics, evolutionary genetics, and genomics. Recent and current projects have involved cedar, spruce, hemlock, *Linanthus*, and bears. Recently completed projects include: 1) Discovery of the molecular basis of the coat color of the Kermode bear, a white bear found predominantly on islands of the B.C. North Coast. A single nucleotide polymorphism is responsible and the locus show evidence for assortative mating. 2) Documentation of the population structure of yellow cedar. We found evidence for ice age refugia both in the Queen Charlottes and in SE Alaska, as well as moderate inbreeding. (3) Documentation of the population structure and patterns of selfing of western red cedar. Selfing is considerable (30-40%) both in seed orchards and natural stands and the population structure shows a strong Queen Charlotte refugia effect with the boundary halfway down Vancouver Island. (4) Documentation of the population structure of lodgepole pine with chloroplast DNA markers. Evidence for recent range expansion was found. Other studies have involved the mating system of spruce weevil, genetic structure of Garry oak, and new developments in estimation theory, involving mating systems, and bulk assays of DNA. I am also one of four PIs that received a 3.5-year Genome Canada grant for genomic studies of spruce and poplar. We have hired about 10 scientists to work in the Forestry Genome laboratory in our Forest Sciences building at UBC. My part involves development of high-throughput genotyping, as well as co-ordination of bioinformatics activities. For the purposes of genetic mapping and eventual quantitative trait locus mapping, we are planting out backcrosses of both hybrid spruce (white X Sitka) and hybrid poplar (eastern cottonwood (*Populus deltoides* Barta. ex Marsh. spp. *deltoides*) X black cottonwood (*P.trichocarpa* Torr. & A. Gray), and possibly others). These backcrosses will become valuable research resource in the coming years as they mature.

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BRITISH COLUMBIA MINISTRY OF FORESTS FOREST GENETICS RESEARCH AND TREE BREEDING PROGRAM

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The British Columbia Ministry of Forests (MoF) forest genetics research program is still maintaining its focuses on forest genetic resource management policy and issues and also conducts tree breeding in species of major and minor economic value. After facing some layoffs, due to government downsizing, we have managed to maintain 38 research scientists, technicians, station staff, and administrators at headquarters in Victoria and at our two research stations, one coastal and one in the interior of BC. The breeding program follows the BC Forest Genetics Council (FGC) business plan, which largely focuses on our main commercial conifer species, but also includes some work on hardwoods and true fir species. Work on gene conservation continues, but largely through co-operative efforts with the Center for Forest Gene Conservation at University of British Columbia (UBC) which is also part of the FGC program.

FOREST GENETICS AND TREE BREEDING PROGRAM

Western Hemlock (Charlie Cartwright)

Considerable progress has been made over the past year in hemlock (*Tsuga heterophylla* [Raf.] Sarg.) genetics. The general focus has been updating breeding values for most series of tests, making initial advanced generation selections, and completing seed transfer trials. As well, shade tolerance testing moved from the nursery bed stage to field testing and investigation of possible resistance to dwarf hemlock mistletoe (*Arceuthobium tsugense*) commenced.

The series of first generation trials established in 1981 and 1993 were measured, leading to new breeding values for 101 parent trees. As well, three advanced generation trials were measured. This, in combination with two similar trials measured in 2000, lead to the selection of approximately 150 advanced generation parents which were grafted in 2001.

In the field, two more advanced generation trials were established. These were installed five years after the initial trials of this type but feature more families. This material was obtained from the Hemlock Tree Improvement Cooperative (HEMTIC) which has planted four more copies of this trial in 2002, to complement the two we provided them previously. An elite population, which features only the top 30 parents in HEMTIC, was also planted. There are four other tests of this material in BC, but this elite installation features a family block design which should facilitate within-family selection. Five similar tests were established in the United States (US) to complement the one for which we supplied material four years ago. This completes the HEMTIC advanced generation testing. Selections from the older tests will commence in 2002 with deployment to orchards expected about 2008.

Support research featured on-going seed transfer testing. To establish best adapted plants requires widespread trials on which to base seed transfer and to approach optimal growth potential. To this end, tests containing a wide array of natural populations as well as tested families were planted on the Queen Charlotte Islands, Nass/Skeena transition, and high elevation North Vancouver Island. This complements other trials deployed in 2000 and three more to go out in 2002. In general, two tests are located in each biogeoclimatic variant of interest, with an attempt to include a mesic site and a more challenging location. From results, a north Coast hemlock low elevation orchard will be designed and information generated to optimize seed transfer guidelines for the Interior and Transition.

High Elevation Hemlock More activity in 2001 occurred in the South Maritime high elevation program than previously. Crossing was limited to seed transfer and gain trial material, but four new tests with 122 poly-crossed parents were deployed and 10 year measurements were completed on 33 others. At this point, data for 135 high elevation parents have been analyzed and the best 32 selected for inclusion in new high elevation orchards. These orchards will carry a gain of about 8%, but with 10-year-old measurements of the 1995 series and the first measurements of the tests just planted, this should improve to about 12% when the orchard is in production.

Western Redcedar (John Russell)

The western redcedar (*Thuja plicata* Donn ex D. Don) gene resource management program includes gene conservation, genecology, tree breeding, and technical support. The following activities occurred over the last year.

Approximately 100 new parents from southern Oregon were cloned and established in the gene archives at Cowichan Lake Research Station. Besides contributing to the *ex situ* gene pool, these parents will also be included in the breeding and testing program.

Ten-year measurements of the open-pollinated progeny trials were collected and are currently being analyzed. Seed was collected from approximately 300 polycross families from breeding conducted in 2001, for a total of 750 families to date. An additional 250 coastal US sources will be bred over the next two years.

To date, 25 progeny sites have been established testing over 450 polycrossed families. An additional 300 families will be established in trials over the next two to three years. All sites were maintained to minimize competing vegetation and deer browsing. Four nutrient-poor sites were fertilized spring 2001. The first series, established in 1998, was measured for 5-year heights the fall of 2001. Breeding values have been officially released for 150 parents.

Technical Support for breeding program

Selfing Studies Field trials comprising 15 F1 families and corresponding S1 and S2 families from 30 random and 30 select lines were established on three coastal sites. The study was designed to evaluate growth and adaptation differences due to genetic selection and inbreeding, and thus the feasibility of utilizing S1 and S2 families in a recurrent selection program.

Stand volumes, originating from various proportions of selfed seed in a seed lot, were simulated using the BC MoF TASS growth and yield model, for different stocking and site indices. On average, for every 10% reduction in selfed seed, stand yield at 60 years improved by 0.8%. These results will help to assign genetic worth to seed lots with reduced selfing.

Wood durability Western redcedar trees were tested for enhanced natural durability by analyzing wood cores for tropolones, in particular the thujaplicans, and correlating to weight loss in soil block tests. It is anticipated that wood durability measures will be developed for 300 clones by the end of this project.

Yellow-cedar Gene Resource Management (John Russell)

Activities for the yellow-cedar (*Chamaecyparis nootkatensis* [D. Don] Spach) gene resource management program involve gene conservation, genecology, tree breeding, and technical support. The following activities occurred over the last year.

All 10 provenance test sites have been measured at 10-years. Preliminary results show continued evidence of almost random population variation with relation to population environmental origins. Changes to seed transfer will be proposed after complete evaluation of the data.

Three annual series of clonal progeny tests were established. Over 5 000 clones from 400 full-sib families were planted. Three to four test sites were established for each series. All sites have high survival and test trees are growing well. Five-year data were collected in 2001 from the first series. Clonal values from 1 587 clones were developed and officially released. Top selections were repropagated for inclusion into operational hedges.

A clonal forestry project is looking at the most efficient technique for maintaining donor stock juvenility and thus rooted cutting quality. The study includes over 100 clones that have been established from seed lot 9 777 every 2 to 4 years from seed and from previously rooted cuttings from the original seedlings. The oldest donors are now 18 years old. Another round of serial propagation was completed in 2001. Two series of trials were established from the hedges. One series, established on 2 sites, is now 5 years old and data on growth, form, and survival was collected. The other series was established on two sites in coastal BC.

Analyses of nursery and field data to-date indicate that clonal variation in rooting and stock quality is more important than juvenility. Whether a donor plant is continually hedged or periodically repropagated varies by clone. However, it must be stressed that all donor plants were healthy and reasonably juvenile, a prerequisite to a successful cutting program.

Siting of Advanced Generation Breeding Orchard Continual monitoring of pollen development and viability at various natural yellow-cedar areas and “off-sites” have yielded some interesting results. Sites that have the coldest winter temperatures have the best pollen quality. As well, areas that have the warmest summer temperatures and the lowest number of frost-free days exhibit the worst pollen quality. Factors affecting yellow-cedar pollen quality may be a combination of: 1) minimal hot days in the summer to stop pollen from maturing in the late summer/early fall and to reduce susceptibility to direct sunlight and fungal damage, 2) increasingly cold months in the fall to slow down pollen maturation to ensure a proper “resting stage” before the onset of cold temperatures, and 3) enough cold temperatures during winter to ensure that dormancy requirements, if any, are satisfied.

Coastal Douglas-fir Breeding (Michael Stoehr)

Coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) Subline breeding for the establishment of third generation seed orchards was the highest priority for the last two years. Controlled crosses involving over 100 parents were carried out successfully and enough seed was obtained in the fall to sow eight sublines containing a total of 78 parents. These 78 parents are also “GCA” tested using an “average breeding value” polymix. Seeds were sowed in the spring of 2002 with an anticipated planting date in the spring of 2003.

Field work in 2001 included site maintenance of progeny tests and the measurement of the realized gain trials established in 1996. Unfortunately, one of the six realized gain plantation sites in the Powell River area burned in April 2001. The height and root collar diameter measurements on the other five sites (Campbell River, Spirit Lake north of Campbell River, Lang Bay near Powell River, Roberston Creek near Mesachie Lake, and Norrish near Harrison) were carried out in the fall of 2001. These tests were established at four different planting densities ranging from 625 to 3 906 trees/ha using three levels of genetic improvement. These were: “Wildstand” controls with an anticipated gain of 0%, “Mid-Gain” families representing the average genetic gain expected in second generation seed orchards (roughly 12%) and “Top-Crosses” representing the best parents crossed with each other with an anticipated genetic gain of 17% in height growth. The results showed that the average gain of the “Mid-Gain” families over the wildstand was 12%, while the “Top-Crosses” outperformed the controls by an average of 17% over all five sites. Competition effects will be evaluated in detail at a later date.

Submaritime Douglas-fir (Transition Zone Douglas-fir) A genecological study on four sub-maritime sites (two in the Pemberton area and two in the Bella Coola area) was established in 1996 to delineate seed transfer zones and to possibly select superior mother trees for orchard establishment. The coastal-interior transition zone is characterized by sharp environmental gradients and local climates that influence growth performance of Douglas-fir. Heights and mortality were assessed on these four test sites. Included in this test were wind-pollinated transition zone families collected along elevational transects in four major drainages as well as coastal top cross families, open-pollinated families from tested and subsequently selected interior Douglas-fir parents, and interior-coastal hybrids. On the best and mildest site (Lillooet River near Pemberton), the coastal top cross families performed very well but were outperformed on the high elevation Railroad site (1 100 m) and the harsher Talchako site. Generally, the interior-coastal hybrids performed well. They appear to have maintained their adaptation to harsh conditions combined with the fast growth of the coastal parents. However, any strategic decisions regarding seed transfer changes and early forward selections may have to be postponed until the seedlings are above the snow line on the harsher sites.

Interior Spruce, Interior Douglas-fir and western larch (Barry Jaquish)

Interior Spruce (*Picea glauca x engelamnnii*) Recent activities have focused on: 1) second generation breeding and 2) maintaining and measuring first and second generation progeny tests, provenance tests, and somatic embyogenesis (SE) candidacy tests. Although 2001 was a light flowering year for interior spruce, 77 crosses were completed in the Phase II Prince George second generation crossing program. This program, which expands on the Phase I program completed by G. Kiss, is designed to combine select parents from the eight smaller populations that comprise the new Prince George Seed Zone. Forty-nine pollen lots were collected and stored for future breeding.

In the first generation open-pollinated tests, four 3-year-old sites in the Ft. Nelson Zone were brushed and measured. Data analysis is complete and results were used to identify parents for establishing the 1.5 generation Ft. Nelson seed orchard at the Skimikin forest nursery. Further seed orchard roguing will occur following six- and ten-year measurements. Select seed lots from Québec and the Eastern North America population at Kalamalka generally performed poorly on these cold, northern test sites.

Six-year measurements were completed in the range-wide white spruce provenance tests at Kalamalka and Skimikin. Preliminary analyses indicated that on these two sites, 23 of the top 30 families originated from the Ottawa Valley. These results are consistent with those reported in other range-wide white spruce provenance tests and suggest that these provenances could be very useful in the south central B.C. spruce program.

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) Eleven test sites in three test series were maintained and measured: Cariboo Transition (CT), West Kootenay Low (WKL), and East Kootenay. Data analyses are complete and results from the CT and WKL have been used to rogue seed orchards and guide second generation breeding. Results from the East Kootenay series will be used to establish a new 1.5 generation seed orchard.

Fifteen-year height measurements were recorded in the Barnes Ck. seedling/steckling trial. This planting compares the growth performance of seedlings and stecklings from a common genetic origin. Differences between the seedlings (7.3 m) and stecklings (7.3 m) for 15-year height were not significant, but the family rank correlation between the two stock types was highly significant (r = .82). In the second generation controlled crossing program, 214 crosses were completed and 301 pollen lots were collected and stored for future crossing.

Western larch (*Larix occidentalis* Nutt) Three sites in the six-year-old West Kootenay Series II progeny tests were brushed and measured. Parental breeding values were estimated by Best Linear Prediction (BLP) and results were used to rogue the West Kootenay/Shuswap Adams seed orchard at Kalamalka. The Series II test population includes 10 open pollinated families from the Tyner Lake marginal population, north of Merritt. These families were all short and ranked in the bottom 10% of the test population.

Table 1. Six-year growth and heritabilities in West Kootenay Series II western larch genetic tests

Site	Mean height (cm)	Range of family mean heights (cm)	Survival (%)	Damage (%)	Individual heritability (SE)	Family heritability (SE)
Cameron Lk.	185.2	101 – 247	88.4	3.3	0.49 (.07)	0.64 (.10)
Miriam Ck.	216.7	114 – 297	68.1	3.7	0.51 (.07)	0.63 (.10)
Sparkle Ck.	283.4	148 – 364	77.9	7.4	0.59 (.08)	0.69 (.10)

In the second generation crossing program, 149 and 75 crosses were completed in the West Kootenay and East Kootenay populations, respectively. A total of 165 pollen lots were collected and stored for future crossing.

Sitka Spruce (John King and Dave Ponsford)

The Sitka spruce (*Picea sitchensis* [Bong.] Carrière) program is changing focus. Field testing of first generation materials for weevil resistance has culminated in breeding values from three series of open-pollinated trials with 235 parent trees. Clonal tests assembled on provenance program information have yielded data on 325 clones from resistant provenances. Emphasis will now be on moving gains into seed orchards and on advanced generation controlled-cross testing to elucidate the inheritance and mechanisms of weevil resistance.

In preparation for these advances, 77 full-sib crosses were completed in 2001, and 600 copies of 48 different families were made through grafting. A test plantation that can function as a breeding orchard was also established. In the field, maintenance was carried out on eight of the more recent trials and a similar number will be measured in 2002. The measurements are on several series. Firstly, growth information will be gathered from an original weevil-screening test near Jordan River. Weevil-free height growths have already been obtained for the same genotypes from a site on the Queen Charlotte Islands. By comparing those data to results from the test that has been through considerable weevil pressure parents that are not resistant but can be considered weevil-tolerant will be identified.

The Maritime low elevation spruce program also includes testing of weevil-susceptible parent trees for deployment to low hazard environments. Trees from the Queen Charlotte Seed Orchard (# 142) were tested along with Charlotte families selected by the United Kingdom Forestry Commission several decades ago. The British trees claim a volume lift of some 15% at rotation and performance in the nursery relative to Seed Orchard # 142 suggest this is so. Growth data for three sites were compiled in 2001. A fog belt site near Tahsis was measured in November 2001 and two further sites on the Queen Charlottes will be measured in March 2002.

Coast/Interior Spruce Transition Zone Spruce is one of the most productive species for the Transition, perhaps due to frost hardiness relative to other conifers. A total of eight trials was established in 2000 and required maintenance, map checks, and, in four cases, brushing in 2001. These installations will provide answers to seed transfer questions. To this point southern provenances of Sitka spruce carrying weevil resistance have proven to be hardy in Maritime biogeoclimatic variants of the North Coast, but of questionable durability for even the mildest Transition ground. These tests will hopefully provide information for seed transfer guidelines for genotypes carrying adequate weevil resistance.

Two new tests of transition spruce were deployed this year. They involved pure Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) which are necessary to meet high seed needs for high elevation south Interior Coast Transition spruce. To assure balance, one test was at 850 m elevation, not more than 15 km from clearly Maritime ground. The other site is at 1 100 m and a similar distance from clearly Interior zones.

Western White Pine – coastal (John King and Dave Ponsford)

The white pine (*Pinus monticola* Dougl. ex D. Don) program is emerging from an organizational phase with much time devoted to obtaining materials and data from various contributors and institutions. Results from different testing series were collated and reviewed. Considerable progress was made in 2001. Almost 300 controlled crosses were completed in the spring of 2001 at the CanFor Seed Orchard in Sechelt. Some 400 plants were grafted based on selections made with results from disease garden screenings completed by Dr. R. Hunt of the Canadian Forest Service - Pacific Forestry Centre (CFS). Scions were also collected from successful plants in field tests established over a decade ago by Dr. M. Meagher then with CFS. Four new field trials were established with test materials also going for screening at the disease gardens still operated by the CFS.

Interior Pine (Mike Carlson)

Lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) The objectives of current controlled pollination efforts are increasing quantity while maintaining quality of second generation pine tree stemwood. Second generation breeding for each of five seed planning zones consists of two breeding subpopulations: one emphasizing volume growth rate and one emphasizing wood relative density (specific gravity). The best first generation progeny tested parent trees for each trait are grouped and intercrossed in factorial sets to produce 65 second generation test families for each breeding objective. Spring 2001 was the fifth season of second generation breeding. We are finished with the Prince George (PG) and Bulkley Valley breeding sets, about 75% complete with Nelson, 40% complete with the Thompson-Okanagan, and will start the Central Plateau (CP) crossing in 2002.

Late spring of 2002 will see the PG second generation family set (~130 families plus controls grown in 2001) planted on three prepared wild sites in the PG seed planning zone. Our regular industry co-operators (Canfor, The Pas, Lakeland, Riverside, West Fraser, etc.) again helped us locate and prepare good test sites.

Lodgepole pine seed orchard expansion grafting continued in 2001 with some 14 000 grafts made, which were directed toward 6 orchard expansions. Overall graft ‘take’ was better than for the year 2000 with about 75%

survival (2000 survival was about 64%). We expect to graft approximately the same number of rootstock in 2002 for the six interior seed orchard expansion projects.

Following on the work of Dr. Sally John in which Commandra rust susceptibility was evaluated in one of our Bulkley Valley progeny tests (Chowsunket site planted 1986) we will grow and plant 60-80 Bulkley Valley seed orchard families along with putatively rust tolerant wild stand seed sources and susceptible control seed lots in 2002/2003.

Western White Pine (interior) White pine crossing continues with the objective of accumulating genes controlling different mechanisms of blister rust resistance into individual trees (45 crosses made in 2001). Host/pathogen relationship theory predicts longer lasting, more secure host resistance to pathogen attacks when genes for multiple resistance mechanisms are present (“horizontal resistance”) versus having a single resistance gene present (“vertical resistance”). Our current white pine seed orchards (coast and interior) contain parents that were progeny screened for single resistance mechanisms (with a single gene for each mechanism assumed). Pathologists recognize four or five separate rust resistance mechanisms. Thus, much of the seed coming from our current orchards will contain genes for two mechanisms and, therefore, result in trees with excellent disease resistance properties. However, for future orchards we would like parents to each have two or more different resistance genes and thus increase the proportion of orchard seed having good horizontal resistance to the rust pathogen. Seventy wind-pollinated families of white pine from selected “putatively” rust tolerant interior parent trees were rust inoculated at the MoF Skimikin nursery summer 2001. Infection rates will be determined in summer 2002. Seventy control-pollinated families from our crossing work will be sown and grown in 2002 for rust inoculation screening in 2003.

Characterization of Adaptive Traits of Interior Spruce Populations From Northern BC (Sylvia L’Hirondelle, Greg O’Neill and Barry Jaquish)

In 2002 a comprehensive adaptation study began to examine the transferability of interior spruce stock in the Prince George seed-planning zone. Testing is needed to characterize adaptive traits of populations from a wide range of source environments and compare them with seed orchard progeny. This will help to verify elevational limits for class A seed and the limits of seed transfer for class B seed. An improved understanding of the genetic variation in adaptive traits can significantly reduce the risk of damage from climate and microclimate extremes at the planting sites and can increase growth and yield. This will help to deliver the best possible field performance from seed orchard progeny. This information can also be used in developing a gene conservation strategy for northern spruce populations.

True Firs (Cheng Ying)

Three long-term provenance tests of amabilis fir (*Abies amabilis* Dougl. ex Loud) were established near Kitimat, Port McNeill, and Jordan River. As a supplement to the BC component of provenance sources, additional collections of amabilis fir seeds were made from seven provenances (70 wind-pollinated families) in Oregon and Washington, US. The seeds were sown the winter of 2002 for three additional long-term tests aimed at the introduction of the southern provenances. The two series of tests will supply the growth and yield projection from genetic selection in relation to site productivity along the north to south coast climate gradient. These tests constitute the core of the amabilis fir improvement project.

Four short-term tests of amabilis and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) are entering their third season now. We are analysing stem elongation, frost hardiness, and data on seed and cone traits for a preliminary assessment of genetic variation. Results indicate substantial variation among provenances and families. This suggests enormous potential to improve growth rate through the selection of superior provenances. However, reliability of selection at a very young age depends on a solid database. Intensive data collection will continue to be the focus.

SEED ORCHARD RESEARCH

Use of Chloroplast DNA Markers in Seed Orchard Research (Michael Stoehr and Helga Mehl)

In co-operation with BC Research (Craig Newton) chloroplast (cp)DNA markers were developed for several commercial tree species of BC. These markers are ideal for seed orchard research as the cpDNA is inherited in conifers via the male gamete (pollen) but is also detectable in the maternal tissue of a seed (megagametophyte). We completed a study on the mating dynamics in a lodgepole pine seed orchard and found high levels of variation in male reproductive success but low levels of selfing and outside orchard contamination.

Currently, we are applying cpDNA markers to evaluate selfing in lodgepole pine orchards after low-flying helicopters mixed up the pollen cloud during natural pollen flight and to determine supplemental mass pollination (SMP) efficacy in an operational setting. Chloroplast DNA markers have also been successfully applied to verify clonal identities and to check the veracity of control crosses for second generation breeding. Polymorphic cpDNA markers are also available for interior and Sitka spruce, western larch, and coastal Douglas-fir.

Western Red Cedar Pollen Management (Joe Webber)

The conditions under which we can successfully collect and store western red cedar pollen are still not completely defined. Seed yield results from pollen collected in 1999, stored one year, and used for pollination tests in 2000 were poor. Year 2000 was a poor pollination year (fresh pollen yields were also low) and heavy abortion occurred. We could not determine if the quality of the pollen collected in 1999 was poor, if our storage conditions were poor, or if the maternal environment of the year 2000 pollination trial was poor. For 2001, we decided to focus on pollen collection conditions and to determine if our operational collection techniques were appropriate.

Results indicated that we were within a reasonable seed yield range for pollen extracted under external environments (outside). Extracting pollen in an inside environment may be somewhat detrimental to pollen quality but vacuum collection has no apparent ill effect. We monitored both temperature and humidity inside and outside and these data were analysed.

Based on information to date, we recommend that western red cedar pollen be extracted under ambient outside conditions (within the cone shed) of higher humidity.

The Effect of Seed Orchard Environment on Progeny Performance of Interior Spruce (Joe Webber)

The environment affects adaptive traits (frost hardiness) and growth characteristics in progeny from the same parents. This phenomenon is called seed orchard aftereffects. In order to determine the magnitude of aftereffects in interior spruce, we created single parent crosses and compared two orchard sites, Vernon and Prince George, to determine the fitness of southern seed orchard progeny on northern plantation sites. If differences in adaptive traits are detected then we want to separate out both location and parent effects.

We have a growing body of evidence to suggest that temperature during reproductive development may explain aftereffects. We are applying different temperature regimes during various stages of reproductive development and have found that progeny from the cool environment have constantly been more frost hardy in both early fall and late spring tests. We have also shown that temperature effects applied during pollen meiosis had no effect on progeny performance.

Enhancing Production in North Okanagan Lodgepole Pine Seed Orchards (Joe Webber)

We are conducting research to improve seed yields in north Okanagan lodgepole pine seed orchards. It is our hypothesis that if pollen supply is not limiting and *Leptoglossus* is controlled then improved seed yields can be obtained. It is our contention that the current drip irrigation system used by many orchard managers limits the volume of root development, which in turn is not sufficient to support the large crown mass. During hot dry weather, either the volume of roots available or the amount of water supplied (or both) cannot meet the tree's demand, particularly during sensitive stages of reproductive development.

To test this hypothesis, we installed a larger irrigation system (more water distributed over a greater area) and an overhead mist system in two north Okanagan lodgepole pine seed orchards.

Our cultural systems (mist only) did significantly improve seed yields at one site in 2000. We also observed increases of first-year cone mass and seed weight at one site. We did not see any effect on second-year cone mass.

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WESTERN WHITE PINE IMPROVEMENT IN BRITISH COLUMBIA

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We are continuing our efforts to investigate resistance in western white pine (*Pinus monticola* D. Don) to blister rust caused by *Cronartium ribicola* J.C. Fisch.

We have established plantations of trees carrying a putative single major gene that is dominant for blister rust resistance (Cr2), which originated from an USDA Forest Service seed orchard in Oregon. Three of the plantation trees have only become cankered recently (after 12 years). One was screened with 42 healthy seed lots and two cankered lots obtained from these plantations. Seedlings from 39 of 42 healthy parents produced a hypersensitive response, characteristic of the resistant Cr2 gene. Two parents appeared to be homozygous for hypersensitivity. Only seedlings with normal spots produced blister rust cankers. None of the cankered parent trees produced the hypersensitive phenotype. So far, the resistant gene Cr2 appears to be stable in British Columbia. We are continuing to screen for homozygous individuals and use these as pollen sources in our seed orchards. We are developing a deployment strategy to minimize losses should this gene fail and a breeding program that will not be dependent on a single gene in the future.

The seed orchards have selections for putative partial resistance traits “slow-canker growth”, and “difficult to infect individuals”. Additionally, the interior orchard has selections from Idaho. Crossing among seed orchard trees has begun (Figure 1) and inoculations will commence in 2002. Inoculations will help give estimates of genetic gain from seed orchards, justification for any orchard culling, and be the start of documented pedigree lines. From the pedigree lines will come an understanding of the underlying genetics of the partial resistances and how best to pyramid these with MGR genes.

We are initiating an understanding of the resistance within some Asian white pines, as this may help guide us to use the resistant genes within western white pine in a durable manner. In 2003 we will inoculate some *P. siberica* du Tour. and *P. strobus* L. X *P. wallichiana* A.B. Jacks.

MOLECULAR STUDIES

We have now characterized "PR-10 gene" - defense responsive gene. It is a large gene family with each member having its own promoter. Three promoters have been sequenced and the function of the one promoter has been fully analyzed. We are now isolating resistant gene analogues (RGAs) from white pines. This will pave the way for isolating dominant resistance (R) genes from white pine. We are also working on two genes involved in the host-pathogen interaction, one from white pine and the other from the pathogen. To examine the targets of these genes we are setting up a yeast two-hybrid system.

Figure 1. Large pollination bags used in Canadian Forest Products seed orchard for the production of full-sib crosses among blister rust resistant western white pine.

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CLONAL MASS PROPAGATION OF CONIFERS USING SOMATIC EMBRYOGENESIS: CELLFOR'S PERSPECTIVE

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CellFor was founded on 1 January 2000 as a result of a merger between Silvagen Inc. and Pacific Biotechnologies Inc. (PBI). Silvagen's heritage can be traced to The Forest Biotechnology Centre at BC Research Inc., a long-standing contract research group that went on to spin off Silvagen in 1996. PBI's roots can be traced back to the privatization of the British Columbia Ministry of Forests' Nursery Program. This resulted in the acquisition of the province's forest nurseries by Pacific Regeneration Technologies (PRT) in 1988, which in turn founded PBI as a private company intended to focus on the commercialization of somatic embryogenesis. From this union emerged CellFor Inc., boasting the impressive operational, research, and development resources of its two predecessor companies.

SOMATIC EMBRYOGENESIS OVERVIEW

Embryogenic cultures have been produced for a majority of commercially important conifer species by various organizations, including CellFor. The somatic embryogenesis process typically includes the following steps: induction, cryopreservation, liquid culture multiplication, somatic embryo maturation, desiccation, germination, and transplanting of embryos to seedling containers for subsequent growth in the nursery.

Induction

Zygotic embryos excised from mature or immature seeds are placed on a sterile culture medium with plant hormones stimulating development of somatic (embryogenic) tissues. At CellFor, pines are induced from immature embryos while spruces are induced using mature stored seed. The tissue developed from each individual zygotic embryo consists of a mass of proembryos (early stage somatic embryos) with one single genetic identity that is capable of continuous proliferation.

Cryopreservation

Embryogenic tissues produced during the induction are frozen in liquid nitrogen and stored. The purpose of this step is to maintain long-term somatic tissue viability in a juvenile condition, i.e., in a state capable of producing embryos. Cryogenic storage, therefore, is essentially a clone bank or gene conservation method of unique genotypes and provides tree breeders and foresters the time required to conduct clonal testing.

Liquid culture multiplication

The induced tissues are exponentially multiplied (commonly known as "bulking up") in a step that represents true cloning. The multiplied tissues are undifferentiated and are used for the actual production of mature embryos (next step). The ability to produce an unlimited number of genetically identical somatic embryos is the key advantage of somatic embryogenesis technology.

Somatic embryo maturation

The undifferentiated tissue produced by liquid culture multiplication is exposed to maturation media where it proceeds through more advanced stages of embryogenesis. As a result, mature, well-differentiated cotyledonary embryos are produced that are similar in all respects to embryos in zygotic seeds. However, high numbers, ranging from tens of thousands to millions of mature embryos, can be produced.

Desiccation and storage

Mature embryos are subject to a desiccation process mimicking natural seed development as they would mature on the mother tree. However, somatic embryogenesis allows for the production of embryos at any time of the year and the desiccation process removes the restrictions imposed by the production of embryos with high moisture content that cannot be stored. Desiccated embryos can be stored and subsequently used to produce large numbers of seedlings at the desired time during the relatively narrow biological window suitable for seedling production.

Sowing and germination

Somatic germinants or embryos are brought to the nursery and sown directly into media under standard nursery culture conditions. The current system involves delivery of somatic germinants into miniplugs. The small cavity size and high density (ca. 4 000 cavities/m^2) of miniplugs enables the germination process to be cost effectively completed in a controlled greenhouse environment. Within a matter of weeks, small somatic seedlings are shipped to conventional container or bareroot nurseries for automated transplant.

The development and improvement of *ex vitro* germination methods are carried out at CellFor by a team of scientists with a wide range of expertise including in-depth knowledge of somatic embryogenesis (Stephen Attree, Plamen Denchev), genetics (Yousry El-Kassaby, Wolfgang Schuch, David Ellis), plant physiology and nursery production (Steve Grossnickle). The company has attempted to use these skills to develop a routine system for the delivery of genetic improvement to plantations using somatic embryogenesis technology.

CELLFOR'S CLONAL TESTING PROGRAMS

An extensive clonal testing program is necessary for successful mass deployment of clones in plantations as it allows selection of clones having superior performance with respect to traits such as wood volume, growth, form, wood quality or disease resistance. Large-scale clonal testing enables selection of a number of unrelated elite clones thus ensuring appropriate levels of genetic diversity in plantations. In order to carry out a clonal selection program, an appropriate design is utilized considering the elite trees to be used as parents for control pollinated families, the number of seeds required to yield an appropriate number of embryogenic clones per family, and the final number of clones to be selected. Typically, desired levels of genetic improvement (relative to the investment in the program) require selection of the top performing 5% or less of the clones. CellFor Inc. has initiated extensive clonal testing programs for loblolly pine (*Pinus taeda* L.), radiata pine (*P. radiata* D. Don), slash pine (*P. elliottii* Engelm.), Sitka spruce (*Picea sitchensis* [Bong.] Carr.) and interior spruce (*P. glauca* [Moench] Voss X *P. engelmannii* Parry) with 3 260 clones from 158 families present in the field (Table 1). More field testing is underway for southern pines, radiata pine and Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco). In addition to field testing, intensive disease resistance screening has been carried out involving forced inoculation of a number of clones with pathogens. The screening includes resistance to fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*).

Table 1. Summary of CellFor's clonal trials to date (excluding joint venture and affiliates)

Species	No. of Families	No. of Clones
Loblolly pine	28	513
Radiata pine	40	936
Slash pine	11	191
Sitka spruce	24	230
Interior spruce	48	1390

Figure 1. Clonal trial of loblolly pine from somatic seedlings (3 years old).

PROCEEDINGS

OF THE

TWENTY-EIGHTH MEETING

OF THE

CANADIAN TREE IMPROVEMENT ASSOCIATION

PART 2

Symposium

Held jointly with the
Poplar Council of Canada and
Western Forest Genetics Association

INTEGRATING TREE IMPROVEMENT WITH SUSTAINABLE FOREST MANAGEMENT PRACTICES

Edmonton, Alberta
July 22–25, 2002

Editors
L.K. Barnhardt and J.D. Simpson

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DU

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DE

L' ASSOCIATION CANADIENNE POUR L' AMÉLIORATION DES ARBRES

2e PARTIE

Colloque

Présentée conjointement avec le
Poplar Council of Canada et
le Western Forest Genetics association

L'INTEGRATION DE L'AMÉLIORATION DES ARBRES À L'AMÉNAGEMENT DURABLES DES FORÊTS

Edmonton, Alberta
22–25 juillet 2006

Rédacteurs
L.K. Barnhardt et J.D. Simpson

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TREE IMPROVEMENT AND SUSTAINABLE FORESTRY: AN INTERNATIONAL PERSPECTIVE

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ABSTRACT

The demands for forests and forest products are increasing worldwide but the resources are diminishing in many countries. General sustainable development and specific sustainable forest management require the integration of economic, environmental, and social factors at the policy and implementation levels. Tree improvement (traditionally based on selective breeding, genetic testing, and propagation) has focused on traits related to rapid growth of economic products; a large proportion of research and development has been conducted by universities and research institutions while applied breeding programs have been established by government forest services and commercial companies.

Recent trends in public demand and government policy have emphasized: multiple benefits from all forests, non-wood products, non-commercial plantings on difficult or degraded sites, and participation by all stakeholders. Tree improvement includes genetic, silvicultural, managerial, and utilization enhancements. An understanding of population genetics and the genetic control of traits is needed not only for plantation tree breeding but for conservation and natural forest management.

Rapidly evolving techniques hold great promise for equally rapidly changing socio-political, economic, and biophysical environments. However, there is major public opposition in some countries to some of these techniques including: introduction of exotics, traditional monocultural plantation silviculture, inter-specific hybridization, cloning, and genetic modification. One major challenge for forest geneticists, tree breeders, and forest managers is to examine the potential benefits and risks of these technologies and disseminate information in ways that policy-makers, the media, and the public can comprehend. The major task of breeders is to establish programs and tree populations that can maintain genetic diversity, demonstrate adaptive flexibility, and meet multiple objectives using techniques that are publically acceptable, economically efficient, and environmentally safe.

INTRODUCTION

It is a great privilege and pleasure for me to give the keynote address at this world-renowned meeting. After about a dozen visits to Canada, I have at last made it to Edmonton (and I shall be here again in November for another conference) and it is great to see so many old friends again. It is also good to be able to take a rather philosophical-political approach to the subject as I gave up bench research at the level of isozymes and terpenes before molecules arrived and field practice when cloning was beginning. It is also an honour to make this my last public address before my official retirement.

Leonard Barnhardt asked me to give an international perspective on sustainable forest management and the role of tree improvement in achieving it. For nearly forty years I have worked in or for tropical and developing countries. Even though located at the top of the world in Oxford, the Oxford Forestry Institute has often been recognized to be at the heart of the tropical rain-forest. I will spread my talk over six major sets of topics: 1) definition and discussion of sustainable development and sustainable forest management, 2) the products and services obtained from forests, 3) the extent and location of the major forest types, 4) the extent of plantations including agroforestry, 5) some global issues affecting forest research in general and tree improvement in particular, and 6) some threats and opportunities for tree improvement.

SUSTAINABLE DEVELOPMENT AND SUSTAINABLE FOREST MANAGEMENT

Among the hundreds of definitions and portrayals of sustainable development, the one by Hall (1993) is as comprehensive yet simple as any. Sustainable development occurs only with the complete integration of biological (environmental), economic, and social factors. It seeks changes in the production and distribution of goods and services so that an increase in welfare can be sustained over time. A similar concept applies to sustainable forest management. The Inter-Ministerial Conference on European Forests in Helsinki, 1993, declared that “sustainable management means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil now, and in the future, relevant ecological, economic and social functions at local, national and global levels; and that does not cause damage to other ecosystems”.

Following the United Nations Conference on Environment and Development (UNCED) in Brazil, during 1992, a number of inter-governmental initiatives were undertaken to determine acceptable criteria and indicators of sustainable forest management for regular assessments and reporting. These addressed the major forest types: International Tropical Timber Organization (tropical forests), Helsinki Process (temperate forests), Montreal Process (boreal forests), Tarapoto Proposal (Amazonian forests), African Timber Organization (African forests), Lepaterique Process (Central American forests), and various meetings between FAO and other international agencies to cover other forest types and the harmonization of criteria and indicators across all types. While the criteria are relatively easily agreed, indicators are numerous, varied between forest types, and difficult to quantify.

The entire history of development of such processes and the path towards a global convention or agreement on forests since UNCED and up to the World Conference on Sustainable Development in South Africa, August 2002, was described in two books produced by the Commonwealth Forestry Association (Grayson and Maynard 1997; Soderlund and Pottinger 2001).

ROLES AND BENEFITS OF FORESTS

Forests contribute to the three groups of factors referred to above.

Economic products include: timber, reconstituted wood (plywood, boards, paper), chemicals (industrial feedstocks, pharmaceuticals, and nutriceuticals), energy (firewood, charcoal, liquid and gaseous fuels), animal fodder and forage and human food, and land banks for future agricultural development. Data on industrial roundwood production in 1994 showed that Canada and the USA produced nearly 40% of the world’s total but data on production and consumption achieved in 1996 and forecast for 2010 by FAO (1999) indicate rising demands everywhere particularly in Asia and Europe.

Environmental services derived from forests include: soil conservation, water and flood control, macro- and micro-climatic control, site rehabilitation, and genetic resource conservation (biodiversity).

In addition to contributing to general national economic development, forests offer many social benefits including: employment and income generation, risk reduction, counter seasonality in food production and employment, diet diversity, human and animal health, education, community empowerment, recreation and tourism, culture and historical links.

MAJOR FOREST TYPES OF THE WORLD

Vegetation ecologists recognize dozens if not hundreds of forest types and sub-types but these can be grouped into six main categories for international and national policy debates: 1) boreal forests in which a single species is usually dominant, 2) temperate mixed forests with several broadleaved species, 3) temperate evergreen forests with a range of coniferous species, 4) tropical rain forests with high precipitation, high biological diversity, and high value hardwoods, 5) tropical deciduous forests with seasonal rainfall, low diversity, and a few dominant species, and 6) tropical dry forests with low rainfall, open stands, and trees of low economic value.

In 1995 the total forested area amounted to 3.45 billion ha (FAO 1999, 2000) approximately equally split between tropical/sub-tropical and temperate/boreal forest types. Given the importance of the world’s forests, why are we worried? The losses caused by shifting and permanent agriculture, fire, logging, and urbanization are substantial and approximate 12–15 million ha annually, principally in developing countries.

THE ROLE OF PLANTATIONS

Even though plantations occupy only 3% of the world’s forest area, almost one third of the world’s harvested wood comes from industrial plantations (approximately one third of which use exotic species) and plantations will have an increasing role in the conservation of remaining natural forests. However, we must not forget the major importance of planted trees in the wide range of agroforestry systems that have been used traditionally or developed recently.

CHANGES IN FORESTRY

During the existence of the three Associations represented at this meeting, there have been significant changes in the policy, institutional, and technical aspects of forestry. The aims and objectives of forestry have changed substantially in the last half-century.

In the 1950s, the primary target was the production of large volumes of industrial wood. In the 1960s, more attention was given to the quality of such wood and this was refined further in the 1970s to the quality of pulp and paper. These targets continue in the new millennium, of course, with increasingly refined techniques for evaluating quality. For example, the Marcus Wallenberg Prize for forestry and forest products research was awarded to Dr Robert Evans of CSIRO, Australia in 2001 for the development of the Silviscan equipment that incorporates X-ray densitometry, X-ray diffraction, and image analysis for the rapid assessment of fibre properties in small samples of wood. This facilitates genetic, silvicultural, and processing improvements. However, at the same time as industrial forestry escalated, in tropical and developing countries more attention was given to rural development forestry and the role of trees in supporting agriculture and human welfare. Throughout the entire last century, considerable attention was also given to the improvement of yields and toward the end of the century the quality of non-wood products such as pine resin.

Since the United Nations Conference on Environment and Development in 1992, a number of developments in other sectors also have significance to the forestry and forest products sector. These include the international Conventions for the Conservation of Biological Diversity, Climate Change, and Desertification. These join the Convention on International Trade in Endangered Species and the World Trade Agreement in having impact on forests and their management objectives. At the same time, a specific debate on policy reform and a possible forest convention is continuing through the Intergovernmental Forum on Forests of the United Nations Commission on Sustainable Development. A major priority for the United Nations collectively and many donor nations individually is food security, poverty alleviation, and human health. There are both policy and technical conflicts between these but they all emphasize the need for research and information into the wise management and benefits of forests and, for many of the forest benefits sought, they demonstrate the opportunities for tree improvement.

TREE IMPROVEMENT CHANGES, CHALLENGES AND CHANCES

Tree breeding has been practiced for over a century and serious, science-based programs for the last half-century. Initially, they followed a fairly common schedule although some stages were combined or telescoped rather than sequential: species trials, provenance trials, pilot plantations, seed stands, commercial plantations, selection, seed orchards, progeny tests, and loop back to selection. These are often visualized in the classic plus tree selection. However, there have been changes in forest genetics and tree breeding parallel to those of the forest industry in general.

In the 1950s, most work concentrated on the choice of species and provenance with some simple mass selection and occasional species hybridization. Through the 1960s there was considerable debate and practice of different progeny test methods and seed orchard designs. The 1970s saw the planning and implementation of recurrent selection strategies and the 1980s focussed attention on cloning through cuttings (for which four staff members of the Aracruz Company in Brazil received the Marcus Wallenberg Prize in 1984) and tissue culture. In the 1990s, three major sets of techniques and strategies emerged: molecular genetic methods, multiple population breeding strategies (for which Gene Namkoong received the Marcus Wallenberg Prize in 1994), and breeding seedling orchards (pioneered in developing countries by my colleague Dr. Richard Barnes).

The development of molecular techniques facilitates several fields of enquiry in ecology, genetics, and tree breeding. These include: taxonomy, systematics, evolution, and identification of species and individuals; genecology and habitat-related genetic variation between populations of a given species; population genetic structure; identification of breeding systems (for breeding, gene flow, conservation, and habitat fragmentation); evaluation and prediction of genetic differences among species, populations, individuals and clones; genetics and functional genomics of pest resistance, environmental tolerance, growth pattern, and chemical and wood properties; and monitoring of biological diversity.

The multiple population breeding strategy offers a number of advantages over conventional and sequential breeding procedures. Several traits can be improved simultaneously, new selected and tested material can be incorporated into breeding populations, inbreeding may be minimized and genetic diversity maintained, the breeding populations and targets can be amended rapidly to cope with changing management, environments and markets, and genotype-environment interaction effects can be identified and used deliberately rather than sacrifice genetic gain.

At a conference organized by the Queensland Forest Research Institute and IUFRO in 1996, I identified a number of challenges for tree breeding in this current century. These included: better evaluation of the costs and benefits of tree improvement in the face of increasing privatization of forestry, closer tailoring of breeding strategies to local and national demands from forests particularly with plantations and including sub-contracted out-grower schemes, maximizing benefits from the tropical plantations that will expand in several countries, changes in genetic resources and ideotypes for the mixed species silviculture that may be demanded and for the increased availability of difficult sites and possible changing climates, closer participation of users and better deployment and control systems for the improved germplasm that will be required from breeding of multipurpose species for a range of products and benefits, appropriate application of genetic techniques to determine optimum conservation strategies for the biodiversity of tree species and other forest organisms, assessment of the impacts of logging and habitat fragmentation on genetic resources, re-evaluation of the large numbers of existing species, provenance and progeny trials to determine the rates and patterns of genetic change with time and across environments, appropriate and economic application of molecular techniques to the estimation of genetic parameters, the identification of quantitative trait loci, the facilitation of genetic engineering, and the control of breeding strategies.

While some of these have been acted upon, others remain as challenges, and still others have emerged. I believe the following offer both threats and opportunities for tree improvement in the foreseeable future.

Multiple Objectives

The multiple benefits obtainable from forests (and demanded in many cases) offer the usual challenge of breeding for multiple traits – the need to develop selection indices that reflect the genetic controls, genetic correlations and economic weights of the individual traits. Marker assisted selection and quantitative trait loci have a major role to play in hastening this process. However, it is particularly difficult when no clear market values or even unequivocal measurement methods exist.

Environmental Change

The existence of climate change is now accepted although the extent is not precisely predictable at global or local scales. The role of trees in carbon sequestration is scientifically and politically established and tree breeders have a major role to play in the enhancement of rates of carbon fixation in plantations themselves and through them by preserving standing natural forests. Climate change will bring with it changes in pests and diseases (exasperated by increasing tourism) for which molecular identification of resistance will be fundamental to maintaining future production. However, other environmental changes are occurring including air and soil pollution and, above all, the need to restore degraded land to either agricultural or forest productivity. Information is urgently needed on the genetic mechanisms of tolerance of adverse environmental conditions including soil nutrient deficiencies or imbalances and extreme acidity or alkalinity.

Gene Resources Ownership and Management

The Convention on Biological Diversity seeks the equitable sharing of genetic resources and the appropriate allocation of benefits resulting from them. Intellectual property rights, including plant breeders' rights, are a major public issue, particularly as they are not recognized or enforced in many countries. Molecular technologies again have a role to play here in finger-printing and variety identification. Purely scientifically there is an increasing problem of maintaining the pedigree of planting stock once farmers take over their own provision.

Exotics, Monocultures and Cloning

The long-standing, common, public antipathy to monospecific plantation forestry is enhanced by the use of exotic species and, more recently, by cloning. The opportunities of capturing the gains from breeding, hybridization, and genetic modification may be offset by public and political decisions to reject these technologies. Geneticists must work with silviculturists to develop not just multi-clonal options but multi-specific plantation technologies to meet these objections, to diversify productivity from a given site, and to hedge against future change in environments, markets, and silvicultural management. This is especially important in developing countries where rural development, agriculture, and agroforestry are more pressing than industrial forestry.

Hybridization

Early work with inter-specific hybridization concentrated on the production of F_1 heterotically superior seedlings often produced in seed orchards with small numbers of clones and without the benefit of cost-effective clonal propagation systems. One of the early problems of exotic forestry and breeding was the breakdown of second and later generations of hybrids resulting in highly variable and generally inferior stock. More recently, the careful selection of species and individual parents, their testing on a range of sites, and their propagation through cloning or controlled seed production have resulted in gains of up to 50% over original parental stock (e.g., hybrids between slash (*Pinus elliotti* Engelm.) and Caribbean (*P. Caribaea* Morelet) pines in Queensland). Also the current trend is to seek complementarity in different traits rather than heterosis in one characteristic; since most traits are intermediate between the two parental values, as Potts and Dungey (2001) stressed for eucalypts. This then requires advanced generation hybrids based on intense selection in large populations and introgression can be accelerated with marker assisted selection.

Genetic Modification

Techniques for gaining an understanding of the genetic basis of traits and for the modification of genotypes are developing at a rapid pace and examples exist of trees modified for chemical, physiological, and anatomical characteristics including some that could have major impacts on growing or utilizing trees. There is, however, intensive public opposition to the deployment of genetically modified crops and trees and indeed to the testing of them in field conditions, particularly in Europe. The precautionary principle is invoked in the light of our lack of absolute proof that there is no risk of using GM crops. This inhibits future research and development of tree crops and processes that could enhance managerial, economic, social, and environmental effects. Such public opposition results in policy decisions inimical to environmentally well-intentioned initiatives such as the certification of forest for sustainable management (see Strauss *et al.* 2001).

Policy, Public, Press and Pounds

Throughout the 1990s, several trends dominated thinking about forestry and the underlying research. Governments increasingly encouraged the privatization of forestry, particularly the management of forests and plantations for industrial products. Multinational companies have expanded their interests in forests and forest products and some have financed significant research, often by collaboration at the pre-competitive stage and in competition later (Burley, 1999). In support of industry in some countries, outgrower schemes have offered economic opportunities for the participation of small land owners and communities. However, many companies are merging and reducing their commitment to research and tree improvement while many industrial plantations are being purchased by insurance and investment companies as short-term speculations with no commitment to finance research.

While industrial forestry has become more privatized, there has been growing concern for non-industrial rural development. National governments, international agencies, and non-governmental organizations have supported the growth of rural welfare through non-timber forest products production, processing, and marketing. All these trends have focused on commercial, national or local development, but there has also been the growing recognition that forests are a global resource for environmental maintenance and economic performance; global needs and institutions may conflict with national needs and sovereignty.

To ensure the continued support for research and development, forest geneticists and tree breeders have to learn to present their work to policy-makers, the media, and the public in ways that they can understand and use. Current pressures are on scientists and academics to publish in peer-reviewed scientific journals and researchers begrudge time spent on public information. Yet, without it, the long-term nature of tree improvement is at risk. With it, tree improvement can offer spectacular contributions to human economic, social, and environmental welfare.

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INVITED SYMPOSIA PAPERS

ALBERTA CONTEXT: ALBERTA FOREST LEGACY AND SUSTAINABLE FOREST MANAGEMENT

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ABSTRACT

Alberta is the fourth largest forestry province in Canada. Alberta's forests cover approximately 60% of the provincial area and the majority are publicly owned. Approximately 65 300 ha are harvested and 85 million trees planted annually. Forestry contributes approximately $8.4 billion per year to the provincial economy and the provincial government has identified forestry as a key sector in its effort to diversify the provincial economy. Basic concepts of sustainable forest management have driven the development of the Alberta forest resource since forest reserves and fire protection regulations were established in the early part of the 20th century. Since that time, additional changes such as turning over of management of natural resources to the provinces, the development of forest inventories, and sustained yield management have all signalled the desire to manage forests on a sustainable basis. With environmental concerns and greater local, national, and international public pressure to manage forests for a broad set of values, products, and services, greater complexity has been introduced through attempts to move toward sustainable forest management. Increased interest in tree improvement and the maturing of tree improvement projects in Alberta have highlighted the need for policy and standards to integrate tree improvement into the sustainable forest management paradigm. To this end, Alberta has initiated the collaborative Alberta Forest Genetics Framework process, which has produced a set of standards to enable tree improvement within the context of sustainable forest management and the guiding principles of the Alberta Forest Legacy Document.

ALBERTA'S FOREST RESOURCES

Alberta ranks fourth in Canada in production of forest products after British Columbia, Québec, and Ontario. The largest sector of the provincial economy is oil and gas. The provincial government has made it a priority to diversify the provincial economy and forestry is a key sector in that strategy. Alberta has vast natural forests, which occupy nearly 60 percent of the province, or approximately 38 million ha. The major forest cover types are boreal, parklands, montane, and subalpine. The major forestry species of commercial importance are white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), black spruce (*Picea mariana*), and jack pine (*Pinus banksiana*). Forestry and related ecosystem services contribute approximately $8.4 billion per year to the provincial economy (Anon. 2001). The provincial annual allowable cut (AAC) is 24.1 million m^3, which consists of 13.7 million m^3 coniferous and 10.4 million m^3 deciduous. Approximately 65 300 ha of forests are harvested annually. Reforestation is mandatory and approximately 85 million trees are planted annually. Essentially all of the reforestation planting (about 99%) consists of white spruce, lodgepole pine, and black spruce.

POLICY HISTORY AND EVOLUTION OF THE SUSTAINABLE FOREST MANAGEMENT CONCEPT IN ALBERTA

The basic ideas of sustainable forest management, in some form or the other, have been entrenched in Alberta's forestry practice and policy since passing of the Natural Resources Transfer Act (NRTA) in 1930 by the federal government. NRTA passed the ownership and the mantle of authority over forests and other natural resources to the provincial government, paving the way for the province to establish its own forestry legislation in the form of various acts and regulations. These have been enacted, modified, and refined considerably over time to accommodate pertinent scientific advances, changing societal expectations and environmental ethics.

Certainly, one of the most important events in the history of forestry in Alberta was the establishment of the Green Zone in 1948. This unique and visionary approach to public land management (Anon. 1988) provided that the major portion of Alberta's forested land would remain available for long-term forest management and, at the same time, be protected from indiscriminate agricultural settlement and development. The success of the 1948 policy is attested to by the relative wholeness of the green zone today, some fifty plus years after its creation, allowing the application of forest management and biodiversity conservation by government and industry, across much of its expanse.

The relative security of the land base, afforded by the establishment of the Green Zone, opened the door for major development in the forest industry; development that required, up front, a strong and secure tenure system upon which to base major capital investment. During the 1950's, Alberta entered into its first Forest Management Agreement (FMA) that in turn provided a sustainable timber base for its first pulp mill, located at Hinton. The FMA grants the right to a company to enter upon and use the land to grow and harvest timber on a sustainable basis (Anon. 1996). In return for these rights, the company assumes the responsibility for carrying out and managing resource inventories, detailed management planning, construction of roads and improvements and, most importantly, the practise of sustained yield through reforestation, all at its own expense. The Alberta FMA has served as a model for use by several North American jurisdictions. Today there are 19 such FMA's that cover over 60 per cent of the Green Area.

Paralleling the FMA system was the development and adoption of the Timber Quota System in 1966. Timber Quotas are, in many aspects, similar to FMA's except that a quota provides a share of the AAC vis-à-vis a specific land area. A paramount cornerstone of the quota system is the requirement for reforestation, through to a free-to-grow condition, hence enshrining the principle of sustained yield across all major forest tenure arrangements.

Until the mid 1970's, sustainable forestry practice in Alberta primarily revolved around establishing sustainable timber harvest levels and AAC's for the industrial wood supply. In the mid 70's, national and international forces started to impact the direction towards broader formulation of forest policy and public accountability. An emerging environmental movement and greater public expectations for responsible resource stewardship demanded increased attention to environmental protection and resource conservation. It was time to begin the transition from sustained yield management to sustainable forest management (SFM).

In response to public demand, Alberta launched an advanced level of resource planning to address the consequences of the accelerating levels of industrial and recreational land use. This process began with a detailed land use and resource allocation plan for the Eastern Slopes of the Rocky Mountains in southwestern Alberta. Public hearings were held by The Environmental Council of Alberta (Environment Council of Alberta 1979) and a policy paper on land management of the Eastern Slopes region was approved by the Alberta cabinet, in 1977. At the time, the Eastern Slopes Policy represented the first detailed land management policy for an area of this magnitude in the country.

The groundwork laid in the development of the Eastern Slopes Policy facilitated the application of Integrated Resource Planning (IRM) throughout the province. The planning process utilizes public involvement and input to develop the end product that provides a blueprint for balanced resource conservation and development.

With the principles of IRM firmly entrenched within Alberta's public land and resource policy, attention was turned back to the Forestry sector. Ironically, the existence of demanding and rigorous integrated resource plans provided financial institutions with the assurances and confidence that Alberta's available timber resources were not only secure, but sustainable as well. During the 1980's, the province embarked on a major expansion of its forest industry; an expansion that catapulted the Forest sector into a major position in Alberta's economy, behind only the Petroleum & Natural Gas and Agricultural sectors.

In consideration of the rapid pace of this expansion the province appointed an Expert Panel on Forest Management. Their report, released in 1990, addressed major issues of public concern involving forest practises, the forest management agreement process, fish and wildlife management, integrated resource management, and environmental conservation. Key amongst the reports' 133 recommendations was that which addressed the need to complete an Alberta Forest Conservation Strategy.

Throughout the 1990's, a number of complimentary initiatives facilitated the development of SFM Policy. As signatory to the Canada Forest Accord, in 1992, the Government of Alberta was committed to the implementation of SFM (Canadian Council Forest Ministers 1995). A number of steps arose from this commitment. First was the definition of SFM through the Criteria and Indicators, published by the Canadian Council of Forest Ministers. About the same time, the Alberta Forest Conservation Strategy was nearing completion, which led to the creation of the Alberta Forest Management Science Council.

The Science Council was charged with the responsibility of developing a clear science based definition for SFM; a definition that for Alberta would meet its obligations to the Forest Accord, would incorporate the goal and vision of the Conservation Strategy, and would carry international recognition. Included in the mandate of the science council was the assessment of the science-base that would be required to change from

Sustained Yield Forest Management.

In carrying out their assignment, the Science Council issued a number of challenges for the implementation of SFM (Alberta Forest Management Science Council 1997). Included in the challenges was the need for incorporating ecological principles at the landscape level in forest management planning, the establishment of representative protective areas, and a reassessment of tenure to ensure landscape units are managed at appropriate spatial and temporal scales. The entrenchment of public involvement in landscape design and the involvement of Alberta's aboriginal communities in the planning of Alberta's Forest Legacy were also issued as challenges.

The Alberta Forest Legacy (Anon. 1998) was released in 1998. It is an implementation framework built upon the many recommendations and considerations of its preceding initiatives. Amongst its key elements, the legacy adopts the principle of Adaptive Management, a key to implementation for its commitment to ecological management utilizing landscape parameters, forest planning based on more collaborative approaches, new research entrenching sound science as a basis for SFM, and commitment to the landbase, stewardship enforcement and monitoring. Enhanced forest management is a key pillar of the legacy, with Tree Improvement being a major component in its delivery.

TREE IMPROVEMENT AND FOREST GENETIC RESOURCES MANAGEMENT IN ALBERTA

A Tree Improvement and Forest Genetics program for Alberta was initiated by the Alberta Forest Service in 1975. At that time, only about one-third of the annual allowable cut was being utilized and the annual reforestation program was small with about four million trees planted per year. The tree improvement program was somewhat unique in Canada as it was conceived as an investment for the future rather than fulfilling current needs at that time. The initial step was development of a comprehensive long-term program plan. This formed the basis for funding, including several million dollars as initial investment from the Alberta Heritage Savings Trust Fund for development of facilities, infrastructure, and research & development. Since that time, long-term funding for the program has been maintained.

Participation by forest companies in the program has been key to its success. Initial co-operative participation was with three companies but this has increased to 14 over the life of the program. There are also well-developed networking and co-operative work arrangements with the University of Alberta, the province of British Columbia, and other national and international research organizations. Tenure and policy changes have been important from the participating forest companies' perspective in order to justify their long-term investment and commitment to tree improvement.

Today in Alberta, there is a well-developed tree improvement program going into its 27th year (Hansen *et al*. 2003). The provincial reforestation program has increased to around 85 million trees planted annually and the provincial allowable cut is virtually fully committed. The present timber management challenge is to increase the annual allowable cut and the provincial tree improvement program is well positioned to contribute to this need.

A key issue in utilizing genetic improvement to enhance productivity on public lands is to balance commercial timber production needs with sound genetic resources management principles. The Alberta Forest Legacy provides very limited guidance on this topic. A need for greater specialised scientific and policy input pertaining to genetic resources was recognised and addressed through two recent initiatives. The first was the formation, in April 2000, of the Alberta Forest Genetic Resources Council (AFGRC) whose mandate is to provide expert advice and recommendations to the Minister of Alberta Sustainable Resource Management (ASRD) on science, policy, and regulations related to the management of the gene resources of Alberta's forests (Alberta For. Genetic Resources Council 2002). The second, was the Alberta Forest Genetics Framework (AFGF) initiative, the main objective of which is to develop a comprehensive policy and standards for forest genetic resources management in Alberta through a collaborative process with stakeholders.

THE ALBERTA FOREST GENETICS FRAMEWORK

The AFGF process was started in April 2001 based on the recognition that management of forest genetic resources was crucial to practicing sustainable forest management and that increased industry involvement in tree improvement necessitated clear genetic resource management policy and standards. The work involved more than 40 scientists and resource management experts representing both industry and government. Five areas requiring development of policy and standards were identified. These were:

1) ownership and access to genetic materials and information for Alberta tree improvement programs,
2) collection, handling, registration, and storage of genetic materials,
3) deployment of genetic materials in the Green Area ,
4) testing and verification of claims for adaptation, genetic diversity, and gain, and
5) requirements for production facilities and crops derived from production facilities.

Initial working drafts for each of the policy and standards areas are now complete and consolidation by the Primary Task Group or Steering Committee is ongoing with the objective to complete reviews and implementation of the AFGF standards by January 1, 2003. Following, is a description of the main themes for each of the five sections contained in the draft “Management and Conservation Standards for Forest Genetic Resources in Alberta” (AFGF) document.

Ownership and Data Access

Ownership of genetic materials collected from Crown land and the information related to those materials constitutes an issue of intellectual property rights with international and national, as well as provincial implications. Further, for biological materials, the issue of intellectual property rights is complex and not yet well resolved functionally or legally. In order to establish an understanding upon which to continue tree improvement work in the province, a section identified as Ownership and Data Access was included in the draft document. The stated goals of this section are to “establish ownership and access rights to forest genetic resources and state the Department’s requirements for access to data on genetically improved forest material to ensure stewardship of Alberta’s forested public land”.

The Ownership and Data Access (ODA) section establishes that trees and tree materials on public land are the property of the province and that ownership by the province applies regardless of deployment method. However, once authorized by the province, physical tree material collected from public land is the property of the collector with the provision that, the Province reserves the right to retain a sample of the collected material for conservation and research purposes. This provides for the central archiving of forest tree gene resources while encouraging knowledge creation and protecting against unauthorized distribution of materials and intellectual property.

Intellectual property, resulting from tree improvement activities from collections made on public land, or from development of materials to be deployed on public land, is to be shared by the Province, forest company, research organization, and/or tree improvement co-operative based on the following principles. Ownership of intellectual property should be based on the degree of effort of participating parties and may require co-operative, commercialization, materials transfer or commercialization agreements. Where commercialization occurs, the Province will endeavor to retain benefits except where material is used for deployment or strengthening of tree improvement programs in Alberta.

The Department is to have access to data and information for all parent material collections made on public land and pertaining to improved stock and research or breeding programs where materials are intended for deployment on public forested land. The Department may refuse to release information in its custody, or to which it has access, where this information is deemed to be confidential or a trade secret.

Material Collection, Handling, Registration and Storage

The goals of the Material Collection, Handling, Registration and Storage (MCHRS) section are that “genetic materials of forest trees intended for operational deployment on public land will be collected, handled, registered, and stored in a way that is designed to:
1) ensure adaptation and diversity,
2) maintain documented genetic identity and ensure materials are appropriately tracked, and
3) ensure that the genetic integrity and physical quality of materials are maintained”.

All genetic materials to be deployed on public Green Area land must be registered with the Department. Under operational deployment, these materials are classified as either “Stream 1” or “Stream 2” materials. Stream 1 materials are those collected from existing stands in the field rather than from a genetic production facility such as a seed orchard or stool bed. These generally correspond to traditional field collections. Stream 2 materials are those produced as part of a “Controlled Parentage Program” i.e., materials produced from selected parents and in genetic production facilities where there are particular concerns about adaptation, genetic diversity, and genetic worth of crops.

Adaptation in Stream 1 seed or vegetative collections is controlled through restricting deployment of native species to the seed zone of collection and by setting standards for the number and size of these collections. Movement across seed zone boundaries requires submission, to the Department, of a request for variance. There are presently 84 seed zones for the province delineated on the basis of the provincial ecological classification system and early results from provenance testing. Each seed zone covers all species originating within the zone.

Adaptation for Stream 2 materials is assured through the delineation of deployment zones. Where local material is collected, tested, and deployed within the same zone, delineation is initially based on ecological information followed by genetic testing. These deployment zones are referred to as breeding regions. Where non-local material is to be utilized, genetic testing precedes deployment and guides delineation.

Genetic diversity in Stream 1 material lots intended for deployment is assured through setting standards for minimum allowable census numbers for collections and registration. The acceptable numbers vary depending on species and their distribution patterns and reproduction.

Genetic diversity in Stream 2 lots produced from Controlled Parentage Program production facilities and intended for deployment is assured through minimum registration standards for effective population size. Where lots have an effective population size (Ne) of 18 or greater, registration and deployment may be unrestricted within the deployment zone. Stream 2 lots with Ne less than 18 are not eligible for unrestricted registration but may be eligible for restricted registration and conditional deployment.

Genetic identity is assured through standards for labeling, transportation, handling, and documentation of lots from collection through processing, registration, storage, and shipping to nurseries or the field. Genetic integrity and quality is assured through a Departmental approval process that sets standards and, where necessary, reviews processing, testing, and storage facilities to ensure that procedures, equipment, facilities, and staff are capable of maintaining the genetic integrity and physical quality of lots to be registered for deployment.

Green Area Deployment

The Green Area represents areas of public forest land that are managed for multiple outputs and under a sustainable forest management regime. The future desired forest, as defined by public input and articulated through the Albert Forest Legacy Document, identifies four types of land use for the Green Area including areas for conservation, areas of forest to be managed extensively, areas of forest to be managed intensively, and areas under disposition for facilities. It is in the area of deployment that genetic issues around adaptation, diversity, productivity, domestication and displacement of wild genetic resources, conservation, forest health, and biodiversity are addressed at both the stand and landscape level.

As a consequence, the goals under the Green Area Deployment (GAD) section of the AFGF document have a broader focus than those for other sections. They state that “genetic resources of forest trees will be deployed within the Green Area in a way that strives to:

1) conserve the genetic integrity, adaptability, diversity, and health of wild and managed populations while recognising that genetic change will occur through evolutionary pressure and deployment,
2) maintain or enhance forest productivity,
3) be consistent with sustainable forest management principles (economic, social, and environmental), and
4) recognize that the Detailed Forest Management Plan (DFMP) or plans of equivalent level, guided by this and other related policies, will determine how deployment will occur.

As stated previously, issues around adaptation for Stream 1 materials are dealt with through standards around collection and deployment within a seed zone system. This seed zone system, where collection and deployment occur within a defined ecological unit, also addresses issues around forest health and productivity and provides an ideal regional unit for conducting *in situ* forest genetic resource conservation activities.

Point seed or vegetative collections made within an elevation range of 100 m and a defined radius may be registered and deployed throughout the seed zone of origin and are eligible, upon approval of the Department, for movement across seed zone boundaries. Where seed supply is a problem, smaller but broader geographic collections may be made and deployed but these are not eligible for out-of-zone transfers. Each disposition holder is required to maintain at least one registered Stream 1 seed lot for each species in each seed zone where artificial regeneration is planned. In order to maintain within-species population variation within seed zones, a maximum deployment number for stock from a registered lot is set and scaled to seed zone size.

Deployment of Stream 2 materials occurs within defined “Deployment Zones.” These may either be “Breeding Regions” where materials are local or “Deployment Zones” where materials are non-local and adaptation to the physical environment or biotic community is of concern. All deployment of Stream 2 material must occur under an approved Controlled Parentage Program Plan. There are currently 20 delineated deployment zones in the province and several in the planning phase.

Adaptation for deployed Stream 2 material is assured through genetic testing as set out in the standards and project Controlled Parentage Program plans. For breeding regions, which are delineated on the basis of ecological information and the targeted zone for collection, testing and deployment, genetic testing is generally concurrent with project development. Where non-local material is being developed for deployment such as exotic species or material from distant provenances, restricted registration applies and testing to determine adaptation is required prior to delineation of a deployment zone and final project development. These non-local materials will be assessed for benefits vs. risks on a case-by-case basis and may have conditions attached to their deployment. Genetically Modified Organisms (GMOs) require federal approval prior to consideration by the Department and the present policy, based on present knowledge and risks, is not to approve deployment.

In order to manage the reduction in genetic diversity that generally accompanies development and deployment of genetically improved Stream 2 materials at both the stand and landscape level, deployment from any given production facility is limited and a minimum Ne is set for individual lots being produced. Individual lots with Ne of 18 or greater are eligible for unrestricted registration and deployment to plantations throughout the designated deployment zone while those of Ne 6 to 17 are eligible for restricted registration and deployment. Lots with Ne less than 6 are not eligible for registration.

Whereas lot Ne is used to assure adequate diversity at the stand level, landscape Ne is managed by limits to cumulative Ne from production facilities. For Stream 2 facilities producing seed, total output over the life of the facility, where estimated cumulative Ne is less than 30, may not exceed 25% of the total area estimated for the target strata over a rotation. Seed producing facilities with estimated cumulative Ne greater than 30 may produce material for deployment on up to 50% of the total strata area. For facilities producing vegetative materials this is reduced to 20% and 40% respectively.

As the area of forest regenerated artificially becomes greater, and the level of deployment of Stream 2 materials leads to increasing domestication, areas of wild forest become increasingly displaced. Recognizing this, efforts are being made under the auspices of the Alberta Forest Genetic Resources Council to develop a provincial forest gene resources conservation plan to conserve wild tree gene resources for the future. Under the draft standards, forest companies are participating in this conservation effort through making materials available to the Department for clone banking and seed archiving as well as setting aside and managing *in situ* reserves in their tenure agreement areas.

Breeding, Testing and Verification

This section of the draft AFGF document sets standards for the research and testing of genetic materials planned for production in production facilities (Stream 2 material) and deployment in the Green Area. Standards, which establish the requirements for Research Program (RP) and Controlled Parentage Program (CPP) plans, are a key feature of this section. RP plans are prepared for Department approval where genetic testing is to provide information related to deployment on public land which is not covered by an existing CPP plan. CPP plans are prepared for Department approval where local material is to be produced and deployed in the Green Area or where the Department is satisfied that risks associated with deployment of non-local materials have been adequately addressed and managed.

The stated goals of the Breeding, Testing and Verification (BTV) section of the AFGF document are that, “forest genetics programs that produce Stream 2 material or information relating to Stream 2 material for deployment on public land in the Green Area shall:

1) use testing, analysis, and documentation protocols that are effective, efficient, and scientifically sound, and
2) be designed to ensure long-term flexibility in direction and development of controlled parentage programs, and
3) produce reliable estimates of genetic gain when gain is included as an objective of the Controlled Parentage Program (CPP) Plan.

In addition to laying out the requirements for development of RP and CPP plans, the BTV section establishes requirements for tracking of genetic materials used in Stream 2 program development, handling of pedigree information, acceptable genetic field test layout, design and maintenance, delineation of deployment zones and species specific seed zones, field test measurements, analysis and reporting, and approval of genetic gain. In setting standards for these activities it stresses the use of scientifically credible methods and the production of reliable estimates.

Genetic gain, as determined through field-testing, is provided to the timber supply analysis process in the form of an estimated gain in height. Through negotiation with the Department and timber supply analysis, Annual Allowable Cut increases are determined and established through an approved forest management plan.

Production of Controlled Parentage Materials

The stated goals of the Production of Controlled Parentage Materials (PCPM) section of the AFGF document are that "Stream 2 seed and vegetative materials of controlled parentage for deployment on public land will be produced":

1) in Department-approved production facilities using established procedures,
2) in a manner that maintains the potential to produce a crop that can be registered with a calculated effective population size (diversity) and crop genetic worth, and
3) in a manner that ensures that documentation and reporting provide verification of claims for registration of materials produced.

There are two main concepts central to the PCPM section of the AFGF document. The first is that any established facility, producing Stream 2 reforestation material for deployment on Green Area land, must have the capability of producing a crop that meets registration requirements. Most of the standards revolving around this have to do with parentage, layout design, and the protection from genetic contamination and environmental hazards of production facilities. The second is that crop production procedures and collection are conducted in a manner that the Ne and crop genetic worth can be calculated reliably for all production lots produced by approved facilities. This assures that genetic diversity requirements and genetic gain estimates are being met by registered Stream 2 crops.

CONCLUSION

The genes of Alberta's forest trees are regarded as a heritage resource of central importance to sustainable forest management. In addition to providing the genetic potential for meeting the requirements of future natural forests, this genetic variation is being used to increase forest health and productivity in managed forests.

The recognition of the importance of these genetic resources has prompted an intensive effort to develop policies and standards through which genetic resources will be managed. This effort, named the Alberta Forest Genetics Framework, has the goal of maintaining adaptation and genetic diversity while enabling increased forest productivity through tree improvement. The Framework is designed to fit within the context of the Alberta Forest Legacy, a broad statement of goals for Alberta's forests.

The Framework is scheduled to be implemented in 2003. Current reviews of tree improvement programs are following standards specified in the Framework. These standards will also be used in developing a provincial plan for gene conservation. Periodic review of how the Framework is planned and adjustments probably will be made as experience accumulates.

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HERITAGE GENETIC RESOURCES AND CONSERVATION – FROM A TREE IMPROVEMENT PERSPECTIVE

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INTRODUCTION

Heritage genetic resources, forest genetic resource management, and conservation of forest genetic resources are a few of the several terms becoming more widely used by forest geneticists and tree breeders around the world as a means of describing how the work of tree breeding has progressed to a 'higher' level. This terminology has arisen over the past several years due to the increasing needs and pressures on foresters to address issues of sustainability, and in our case, sustainability of forest genetic resources. The business of 'tree breeding' seems no longer simply the business of recurrent selection with a few commercially valuable tree species.

As far back as the early 1980's, Gene Namkoong, (e.g., Namkoong 1984) was describing these general ideas and needs within the forest genetics community and laying out many approaches for conservation and breeding. Jeff Burley (in these proceedings), outlined many more of Professor Namkoong's theoretical and humanistic contributions to our understanding of conservation and breeding in forestry. However, many of us, and many of our agencies, were not at a point in time where these considerations warranted much serious energy. As well, we were struggling with more basic problems of successfully executing the fundamental selection, breeding, and testing approaches being adapted from breeding of non-tree species. Nevertheless, many agencies now look at tree improvement in a larger context, irrespective of the historic reasons for the delay.

Although gene conservation has been talked about in forest genetics circles for many years, few initiatives really developed into anything formal or well spelled out. For instance, while it was desirable to think of wild population reserves as being a prudent thing to have around, it was not clear why, how or when they might actually become useful. Moreover, it was clear from short and long-term selection experiments that ample genetic variation was still available in small breeding populations of maize, fruit flies, etc. even after many generations of selection. The thinking around conservation and breeding, however, has evolved substantially from what I refer to as conceptual models of conservation and breeding. The conceptual models served the tree breeding community well for this period of time, but clearly these concepts are difficult to apply in practice and were no longer scientifically and economically defensible.

CHANGING VIEWS OF CONCEPTUAL MODELS OF GENE CONSERVATION

At the 1995 Canadian Tree Improvement Association meeting in Victoria, British Columbia (BC), conservation issues were addressed. Carson (1995), in his summary paper of the meeting, presented some of the versions of the older and newer conceptual models. These showed a clear progression in thinking, but they also showed that all components (*in* and *ex situ*) seemed necessary. There might be overlap in their objectives, but there was quite a bit of disparity in how genetic variation may be conserved or developed over time. Since most of the principles of conservation and breeding are based on quantitative genetic theory, it seemed reasonable that the next logical step was to spell out some numerical targets so that what we were expecting to conserve would be clear.

A PRACTICAL QUANTIFICATION FRAMEWORK TO AID CONCEPTUAL MODELS

A few years ago, at the symposium in honour of Professor Namkoong (Aitken *et al.*, 2001), I suggested one approach that would allow for more structure and quantification of where and how we would be expecting to conserve different types of genetic variations important for current and future management objectives (Yanchuk 2001). Figure 1 presents a relatively simple graph, based on binomial sampling theory, which could allow us to assess how many copies we may have of some gene in a particular population. The expected original gene frequency in the population, and whether it was segregating as a dominant or recessive allele (as well, these must have major effects), and how many copies one would be interested in capturing, largely determine the size of the population that is needed. Namkoong (1982, 1988) established similar sampling requirements for low frequency genes from populations and those in Yanchuk (2001) are only slight modifications based on a different objective and to meet some of our local needs in BC.

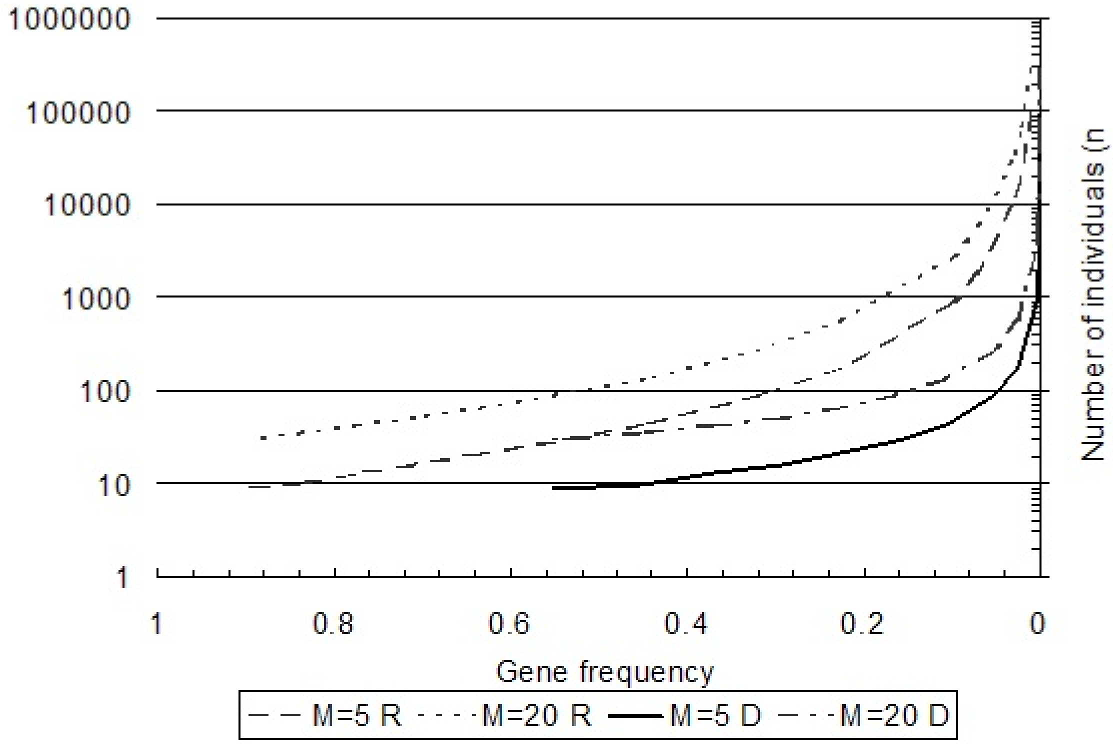

Figure 1. Plot of number of individual trees that would be in a conservation population of interest (n) (in either *in situ*, *inter situ*, or *ex situ*) that would capture either 5 or 20 (M) copies of alleles that are recessive (R) or dominant (D) for genes at certain frequencies in the original base population.

In many ways, this of course reflects an almost 'cartoon' view of what we know about genes (or don't know) and their impact on the phenotype. However, it does provide some guidance as to what may be reasonable numbers of individuals to conserve/maintain for *in situ* populations. One doesn't need to look at Figure 1 to recall that it is quite easy to obtain several copies of a gene at intermediate frequency even in a small sample of genotypes. So, by default, gene conservation largely becomes a problem of maintaining several copies of rare or low frequency alleles.

For quantitative genetic variation, the work of Lynch *et al*. (1995) has shown that in order to keep wild populations evolving, growing, and turning over generations without much help from us (but not in all cases), effective population sizes of around 1000 might be necessary. This is largely based on the need to keep a balance between mutation and drift in natural populations. Considering that tree populations generally do not have effective population sizes equal to census population sizes, we could set a target number, to be safe, of around 5 000. If this is the case, i.e., an organization wants to maintain *in situ* populations of ~ 5 000 individuals, then all they have to do is look up in Figure 1 to find what could be expected by way of 'conserving' low frequency alleles, in the current population.

DOCUMENTATION OF *In Situ* GENETIC RESOURCES IN BC

Several years ago, we attempted to document the current *in situ* status of conifers in the network of protected areas in BC (Yanchuk and Lester 1996). We found that, generally, most conifers are well protected in BC. This, of course, varies greatly among species and whether the type of conservation present is desirable, in terms of a good mix of *in* and *ex situ*.

It seems quite logical that current computer and software improvements in geographic information systems can allow us to raise this kind of documentation and monitoring work to a much higher and more dynamic level. For instance, at the University of British Columbia, the Centre for Forest Gene Conservation was established and the survey reported by Yanchuk and Lester (1996) is being updated using more modern approaches with GIS (Hamann *et al*. 2003) with various types of inventory data. This, in effect, allows us, for each species of interest, to numerically 'fill in' the old 'gene conservation pyramid(s)' (Carson 1995) or where the line may be for a species for *in* or *ex situ* in Figure 1. These efforts will continue to detail the protected status of important tree species and allow a much more dynamic approach for keeping track of the inventory of protected areas over space and time.

CONSERVATION, MANAGEMENT AND USE OF QUANTITATIVE GENETIC VARIATION FOR BREEDING, OR *Ex Situ* POPULATIONS

The largest impetus for attempting to build integrated strategies for conservation of rare and low-frequency genes, comes from the fact that most organizations will be challenged by financial limitations to keep many large *ex situ* populations (or more importantly, large breeding populations). This is particularly true in BC where we currently have over 40 programs with *ex situ* type collections and testing underway, all being directed by 6 tree breeding scientists.

We have viewed the problem of the 'conservation' of genes and genetic variation in breeding programs as a substantially different problem than conserving genes in non-select populations. This is primarily due to the fact that we are actively changing the frequency of genes at targeted loci, so it is a matter of when genetic variation will be depleted, rather than "eroded." Erosion of genetic variation, it could be argued, is what happens with neglect or ignorance on the effects of genetic drift for loci not affecting the trait under artificial selection. In fact, genetic variation may increase in the first few generations for our traits of interest, as positive alleles reach mid-frequency. This, of course, is a genetic detail of great complexity and will generally not be known.

As well, many short- and long-term selection experiments have shown that genetic variation is not substantially reduced over the short term (i.e., 5-10 generations), even in population sizes of a few dozen (Namkoong *et al*. 1988). Surprisingly, this is even generally true in the longer term (i.e., >10 generations), and is largely expected to be a function of new genetic variation arising from mutation (Barker 1995), amongst other mechanisms that are known to generate or maintain genetic variation (Rasmusson and Phillips 1997). So the question for tree breeders is, how large should population sizes be, if we assume that after 10 generations there will be genomic mechanisms in place which will maintain genetic variation in case it is needed?

Various computer simulation models have been used recently, by tree breeders, to examine some of these questions, particularly how it relates to population size and structure. For instance, Mullin and Park (1995) and McKeand and Bridgwater (1998) have approached these questions from both parameter and locus based modeling. Without going into much detail of the results of these studies, as there are many permutations and combinations that one can consider, the basic results suggest that for one trait a population size of a few dozen (e.g., 30-50) may be more than adequate for several generations of breeding. It is interesting to note that Namkoong was proposing numbers in this range, and even lower, for some time (Namkoong *et al*. 1988). Of course, each organization has to accommodate specific needs with respect to seed or vegetative production (e.g., subline structure to minimize related matings in seed orchards). But population sizes larger than this would be justifiable for program reasons, rather than on conservation of genetic variation.

IDENTIFYING USES AND INTEGRATION STRUCTURES OF *In*, *Inter* and *Ex Situ* POPULATIONS

This then leaves us with the question of what is the value of conserving genes in other sets of populations, if we think large *in situ* reserves are adequate for low frequency genes and small breeding populations are adequate for long-term breeding? To be sure, the genetic variation that is captured in the 5 000 tree population (typically an *in situ* population) is also what is present in the population of ~ 50. However, it will be in a very different (i.e., unselected) genetic background and perhaps soon almost irrelevant as a useful commercial population (assuming our selection objectives target the same traits over many generations). But, as we have pointed out previously, many low frequency genes will not be present in small breeding populations (which is what we have said is the main function of *in situ* populations). Therefore, it seems useful and worthwhile to maintain or structure various forms of 'weaker' *ex situ* populations (I have borrowed the term *inter situ* from some of the agriculture literature (see Blixt 1994)) that could accommodate this gap between 50 and 5 000. (These numbers themselves are not etched in stone and can be determined based on what is available and affordable to the organization).

It is fortunate that, for many tree improvement programs around the world, substantial investments in genetic selection and testing have been made in wild populations, either for provenance or progeny testing. Although most breeding programs now concentrate on elite populations identified from these 'base' populations, the base or *ex situ* research 'real estate' (e.g., provenance test, 1st generation open-pollinated progeny tests, clone banks etc.) are substantial and could generally be of population sizes of a few to several hundred. For instance, the Western Gulf Tree Improvement Co-operative (WGTIC), a few years ago, decided that it would maintain all 3 000 original parents in clone banks as gene conservation populations (Byram *et al*. 1998). This would provide the WGTIC with a means of conserving many of these low and mid-frequency genes in a much more desirable genetic background as much is known about the parents. Progeny tests themselves could be considered useful conservation populations. As they are on multiple sites, they sample more recent environments and, because of experimental field designs, would have good heritabilities for any future trait of interest (e.g., Lipow *et al*. 2002).

Many ways of presenting or documenting such information for a particular species in a particular zone can be considered. The 'seamlessness' among the various populations that are being managed in this genetic hierarchy will vary, based on many factors, but it will be possible to state what kind of conservation is expected of each. Around these fundamental data, management plans can be developed, which really do show that the genetic resource is being managed, or at a minimum, thought about in terms of genetic resource sustainability.

SUMMARY AND CONCLUSIONS

There are many new pressures on forest geneticists that will continue to challenge the assumptions of plans, ranging from: 1) forest certification standards and acceptance of such plans to these schemes, 2) developing practical genetic criteria and indicators (C& I) among many of the C & I processes being considered in the world, to 3) developing deployment strategies for rapid climate change threatening the adaptive capability of existing natural and synthetic populations of forest trees (Rehfeldt *et al*. 2002). These new pressures will likely cause us to re-examine many of the strategies and techniques we currently use in tree breeding and forest genetics e.g., test designs in extreme environments, decision support tools aimed at intercepting appropriate changes in climate with the appropriate populations, and so on.

It may be safe now to say that genetic resources from a tree improvement perspective are not any different than from a conservation geneticist's view, or if they are, the differences are small and probably due to local details. As long as gene resource management is based upon sound considerations of the conservation of various types of genes (e.g., low frequency, high frequency, dominant, additive), of currently known, and for potential future value, then there can be little argument that an approach can be wrong.

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INTENSIVE TREE BREEDING TO ENHANCE FIBRE PRODUCTION

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INTRODUCTION

Plantation forestry is rapidly displacing the harvesting of the world's natural forests. Jeff Burley (these Proceedings) has pointed out that 40% of the world's fibre supply now comes from the 3% of forests established to plantations. Softwood plantations, principally of pines, contribute a major share of the plantation resource and these are largely grown in the temperate regions of the U.S., Europe, northern and southern S. America, and Oceania. Pine plantations in the southern U.S., Chile, Australasia, South Africa, and (more recently) Brazil have been intensively managed for periods of up to 60 years, and their productivity, relative to natural stands, has been high (Figure 1).

Until recently, the highest growth rates have been achieved by *Pinus radiata*, particularly as grown in New Zealand (NZ) and Chile, with yields averaging up to 25 m^3/ha/yr. However, growth rates of *Pinus taeda* in the fertile soils of northern Argentina, Uruguay, and southern Brazil can sometimes exceed these values, and some of the Southern Pine hybrids (e.g. *Pinus caribaea* X *Pinus elliotii*) show similar potential in these regions. Growth rates of *Pinus taeda* in the southeast U.S. have typically been low (average 12m^2/ha/yr), but recent attention to optimizing silvicultural inputs at establishment have dramatically increased yields to those more typical of radiata pine (R. Kellison, pers. comm.).

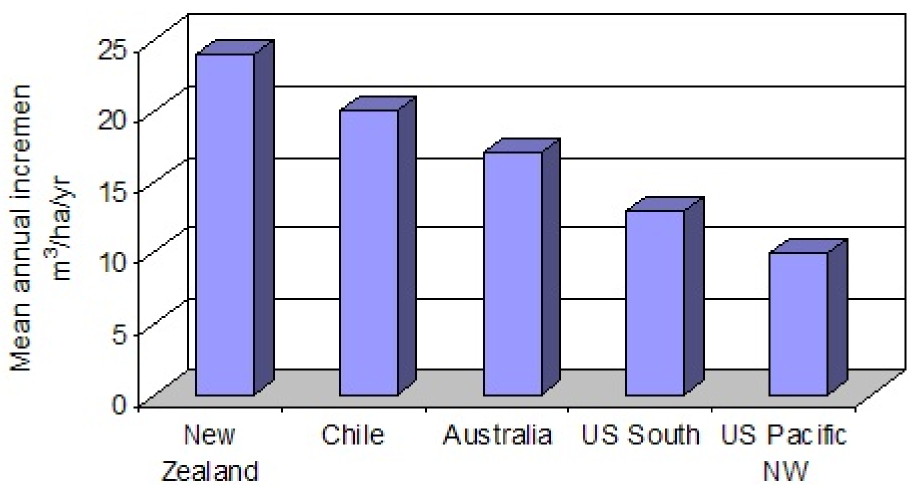

Figure 1. Softwood growth rates.

Tree breeding programs have been a natural outgrowth of the move towards more intensive forest management. Pine breeding began in the southern U.S. (Texas and North Carolina) in the early 1950s, initiated by Bruce Zobel, and these programs were quickly followed by programs elsewhere in the U.S. and in NZ, South Africa, and Australia. While early tree breeding programs borrowed from the breeding methods developed for corn, it soon became apparent that the breeding of wild-type, out-crossing perennials required different selection strategies and mating designs than for domesticated, inbreeding annual crops, and that tree breeding had much more in common with the breeding of large livestock animals, particularly, cattle. Tree breeders have since developed methods that require a blend of good experimental design, recurrent selection methods, and extensive use of quantitative genetic methods derived from and around R. A. Fisher's original Infinitesimal Model – which assumed that observed gene action is the product of the accumulated, additive effects of numerous genes.

Intensive tree breeding can be defined as ***'tree breeding methods that aim to achieve maximum genetic gains in traits of economic importance in the shortest possible time'.*** This paper will examine how intensive tree breeding is being implemented, using the radiata pine breeding program in NZ as an example.

RADIATA PINE IN NEW ZEALAND

Pinus radiata evolved in the maritime climate of coastal California and will normally grow well only in conditions that closely mimic that environment i.e., near-coastal, low-elevation lands, well-drained soils, moderate temperature range, and moderate precipitation spread evenly through the year. Almost all of NZ's 1.6 million ha of radiata pine plantations grow under such conditions. A typical stand of radiata pine will yield between 650 – 800 m^3/ha of wood and fibre by or before age 28, with trees averaging about 2.4 m^3 and yielding the forest grower approximately NZ$ 150 – 200/tree, or between NZ$ 45 000 and NZ$ 60 000 per hectare (NZFOA).

TREE BREEDING

Tree breeding offers growers genetic gains in many traits of economic importance including growth rate, log quality (as affected by stem straightness, leader health, and branching characteristics), disease resistance and wood quality. To these, some programs will add traits affecting fibre yield and quality. These traits have invariably been shown to be under moderate-to-strong genetic control and are, therefore, amenable to recurrent selection methods employing progeny testing. Growth rate improvement has received most emphasis in the past and some impressive gains are now being confirmed in stand-level trials at, or close to, rotation age (for example, Carson *et al*. 1999 Table 5) and Table 1 below.

Table 1. Actual and percentage genetic gain in *Pinus radiata* volume growth at age 17 years

	Climbing select[1]	Open-pollinated SO[2]	Control-pollinated SO[3]
Age 17 volume (m^3/ha)	338	394	443
% gain vs. base	2.3	18.8	33.8
Age 28 % gain (est.)	2	14	23

[1] good trees selected for seed collection in land race plantations
[2] grafted trees of progeny tested parents with seed arising from wind pollination in seed orchards
[3] grafted trees of progeny tested parents with seed produced by specific pair crossing

Traits of pines not usually amenable to conventional selection include branch size and angle, stem shape (taper and 'roundness') and traits like lignin composition, and herbicide and insect resistance tend to be considered instead as candidates for R&D utilizing genetic modification (GM). Tree breeders faced with a new candidate trait will routinely look at genetic parameters of the tree population for evidence of moderate-to-high levels of additive genetic variance and heritability and relatively low levels of genotype-by-environment interaction before proceeding. A substantial number of traits fail to meet these specifications. However, for traits with these characteristics, breeders have made substantial improvements over the past 50 years with, for example, many programs reporting yield increases in the order of 1% or more for each year of tree improvement effort and with similar levels of gains in other traits.

Tree breeding gains are not guaranteed and can easily be neutralized by the application of poor siting decisions and poor silviculture. Site and silviculture effects are invariably much larger than the effects of genetic improvement. For example, in one NZ study (Carson *et al*. 1999) differences in tree volume growth arising from site and silviculture were on average 8 times larger than genetic differences between improved and unimproved seed lots. Such strong site and silviculture effects might be expected to contribute to equally strong interactions of rankings of improved genotypes, but there is little evidence for this (Carson 1991), particularly in traits affecting log and wood quality and disease resistance. Most exotic pine breeding programs have been successful in achieving gains from single national breeding programs for a broad range of breeding objectives (White and Carson, in prep.).

VALUE OF TREE BREEDING

As tree breeding programs have matured, it has become evident to growers that the costs of breeding represent an investment in the plantation resource and one that should be considered alongside other components of investment aimed at achieving positive financial returns from plantations. Tree breeding programs are long-term and expensive. For example, an estimated NZ$ 30 000 000 is the cost incurred by the New Zealand Forest Research Institute (NZFRI) in tree breeding for the 30 years between 1959 and 1989 (J. Buddle, pers. comm.). However, despite these high costs, benefit/cost estimates have usually been large and positive (e.g., Shelbourne *et al*. 1989) given the large multiplier effect associated with broad deployment of improved genotypes in plantations. Tree breeding programs are, therefore, not inherently difficult to justify on an overall strategic basis, but it is reasonable to expect breeders to defend their decision-making relating to investment in specific breeding goals and traits. This can be done using standard forms of investment analysis, as are widely-used in exercises of forest planning and valuation (e.g. Casasempere 1994; Liley 2000).

There are published examples of the use of investment analysis in tree improvement decision-making (Carson 1988) and these include more recent projects aimed at determining economic breeding goals for tree improvement programs (e.g., Chambers 2000). The latter analyses concentrated mainly on the optimization of production systems versus comparisons of the value of pursuing alternative traits *per se*. However, comparisons at a per hectare level can be extremely valuable in enabling the inputs of measurement costs and age of assessment to be related to the outputs of physical yields of timber and financial returns, in order to determine which mix of selection traits can best be used to optimize plantation value at all levels of national, regional, and site differentiation. This is particularly so when growers with differing economic objectives have the opportunity to deploy discrete pine families and clones to specific sites and silvicultural regimes, as is now the case, for example, for radiata pine growers in the NZ forestry sector.

Table 2 summarizes results of a simple trait-by-trait investment analysis for alternative breeding objectives for radiata pine in NZ. They rely on simple assumptions as to content and timing of management operations, and log and timber yields and values and prices for two contrasting silvicultural regimes. Approximate estimates have been made of the per hectare value in PNW NZ$ terms to illustrate how this simple method can enable breeders and growers to make sensible decisions about their priorities for breeding and deployment of improved genotypes.

Despite the imperfections of this approach, a few things become immediately evident from Table 2, for example:

1) When conservative gain estimates are used, value gains to the forest grower are low, relative to those that can be achieved further down the ‘value chain’. The benefits will accrue almost entirely to the ‘downstream’ processors and sellers of wood products, unless growers are provided with incentives in stumpage prices.
2) It is often (but not always) valid to assume that value gains for different traits will be cumulative. For the example given (and the traits with values attributed) this might provide estimates of value gains of approximately NZ$ 2 000/ha (in PNW terms) for each of the two alternative regimes.
3) Putting aside considerations of risks and uncertainties, this in turn suggests that the grower can afford to pay up to, but no more than about NZ$ 2 000/ha for the improved planting stock or up to NZ$ 2.00/plant (if we assume a planting rate of 1 000stems/ha). Given that NZ growers are currently paying up to NZ$ 0.45/plant for the best-available improved genetic stock, there is not a lot of excess room here for recovering the sunk costs of tree breeding.
4) Gains in value from improved log and wood quality can be substantial and can match or even exceed value gains from increased wood volume.
5) The value of increased fibre yield has only a small impact on value in the NZ market given the emphasis in this market on the production of timber for export vs. processing of pulp and paper products onshore.
6) More work is needed in evaluating value returns from improvement in log and wood quality traits affecting timber strength, stiffness, stability and durability, as well as the suite of new traits known to affect the value of appearance–grade timber.

Table 2. Cumulative benefits from tree improvement

Goal	h^2	Gain expected	Estimated value NZ$/ha NPV: Appearance	Estimated value NZ$/ha NPV: Structural/pulpwood
Timber volume (m^3/ha)	0.25	20%	559	759
Fiber yield (kg/m^3)	0.8	7.5%	24	40
Reduced costs	-	25%	525	155
Strength	0.8	+	+	++
Stability	0.4	+	+++	+
Timber stiffness	0.6	25%	+	900
Reduced sweep	0.3	20%	120	120
Clear cuttings	0.4	25%	400	0
Dothistroma resistance	0.25	15%	75	75
Pitch canker resistance	0.25	25%	60?	60?
Appearance	+	++	170?	0

INTENSIVE TREE BREEDING

Elements of Intensive Tree Breeding

Some of the elements that are contributing to successful tree breeding of radiata pine in NZ are:

1) elite breeding populations,
2) control-pollinated seed orchards,
3) focus on wood quality,
4) effective screening of progeny,
5) clonal forestry,
6) targeted deployment of improved plants, and
7) biotechnology applications.

Elite Breeding Populations

The concept of using elite populations is now a major element of the breeding program for radiata pine being carried out by the Radiata Pine Breeding Company (RPBC)(Jayawickrama and Carson 2000). The *P. radiata* elites comprise between about 24 and 40 top-ranked parents which are assortatively mated for specific breeding goals. They include elites for:

1) *Dothistroma* resistance,
2) general-purpose,
3) structural, and
4) appearance.

The parents are separated into two independent sublines, such that breeding is carried out through mating within the sublines while out-crossing between the sublines will restore unrelatedness among progeny intended for deployment and will thus avoid risks associated with inbreeding. Elites are managed in essentially a 'rolling front' manner, in which new elites are developed and tests established without attempting to turn over the overall breeding population within the same time period. The main benefit expected from the elites will be the ability to capture gains more quickly from focusing on specific breeding goals and carrying out assortative mating. Inbreeding will accumulate within elites if they are maintained unchanged for several generations, but this will be countered by regular infusions from both the other elites and from the underlying 'Main' breeding population (Jayawickrama and Carson 2000).

Control-pollinated Seed Orchards

Seed from control-pollinated (CP) seed orchards now comprises the main source for improved genoypes of radiata pine in NZ pine plantations (MAF 2001). Genetic gains from CP orchard stock have been demonstrated to substantially exceed those from open-pollinated (OP) orchard stock in numerous studies (e.g., Table 1) and have also provided significant benefits in terms of the flexability of matching the deployed material to grower's goals (Carson 1986a). Aggressive competition among seed producers in NZ has driven down the costs of controlled pollination such that CP seed can now be sold for less than NZ$ 2 500/kg. While the per plant seed cost (assuming 20 000 plantable seedlings/kg of seed) of NZ$ 0.125 is usually seen as a disincentive to plant CP seedlings directly, the cost-effective multiplication offered by multiplication using rooted cuttings techniques (Menzies and Aimers-Halliday 1997) allows the costs of CP seed to spread over an average of around 50 cuttings per seed, making it easily affordable.

Focus on Wood Quality

New Zealand tree breeders have been placing increased emphasis on wood quality of *P. radiata* since the mid 1980's as evidence has accumulated of the negative impacts of wood quality of dramatic reductions in rotation age coupled with aggressive 'direct sawlog' regimes aimed at maximizing the production of clearwood on heavily pruned and thinned pine stands. These effects have been further exasperated by a trend towards planting pines on former agricultural land, usually on very good sites for growth and with a history of heavy fertilizer applications. If this were not enough, the problem was further confounded by the widespread use of open-pollinated seed orchard material which happened to contain a high representation of parents with unusually low wood density. This effect alone accounted for a 5–10 kg/m^3 decrease in average wood density on many sites.

The results of a large amount of research effort have led to a strong confirmation of the importance of wood quality (particularly wood density) in achieving wood products that are 'fit for purpose' and has highlighted the five specific areas in which radiata pine needs substantial improvement, i.e., for timber:

1) Strength – which is important for structural timber, can be estimated as Modulus of Rupture (MOR), and assessed on wood density from discs.
2) Stiffness – which is important for structural timber, can be estimated as Modulus of Elasticity (MOE), and assessed using acoustic measurement tools on logs (although basic wood density is still the best predictor of tree stiffness).
3) Stability – which is important for both appearance and structural timber. Both micrifibril angle (MFA) and grain spirality influence stability. Screening includes the Spiralometer and acoustic tools.
4) Durability – which is important for weather-firmness.
5) Appearance – which is important for reducing defects in clearwood and includes resin pockets and streaks, internal checking, compression wood, etc.

For pulp and paper and other reconstituted products:

1) Fibre yield – which is important fro Kraft and TMP.
2) Fibre coarseness – for improved paper quality.
3) Fibre length – also important, but is usually considered adequate for most pines.

Effective Screening of Progeny

Effectiveness of screening progeny in family trials is comprised of achieving the optimum combination of earliness and cost-effectiveness in the selection process. Conventional tree breeding for growth rate has usually involved selection of candidate seed orchard parents based on progeny performance at between one-third and one-half rotation age (White and Carson, in prep.) which, for radiata pine in NZ, implies selection between about age 8 and 12 years. Studies of both age/age correlations and the value of early financial benefits have led to NZ breeders moving to a younger age of selection, of around age 6 years for families and possibly even younger for selecting clones for clonal forestry. Resistance to the needle-blight fungus *Dothhistroma pini* can be reliably determined by age 3 in field trials (Carson and Carson 1989), while the examination of typical age/age correlations for family-level differences in average wood density indicate that this trait can also be selected for by age 6 or earlier as illustrated, for example, from average wood densities for a set of improved radiata pine families at age 20 in NZ's Central North Island (Figure 2).

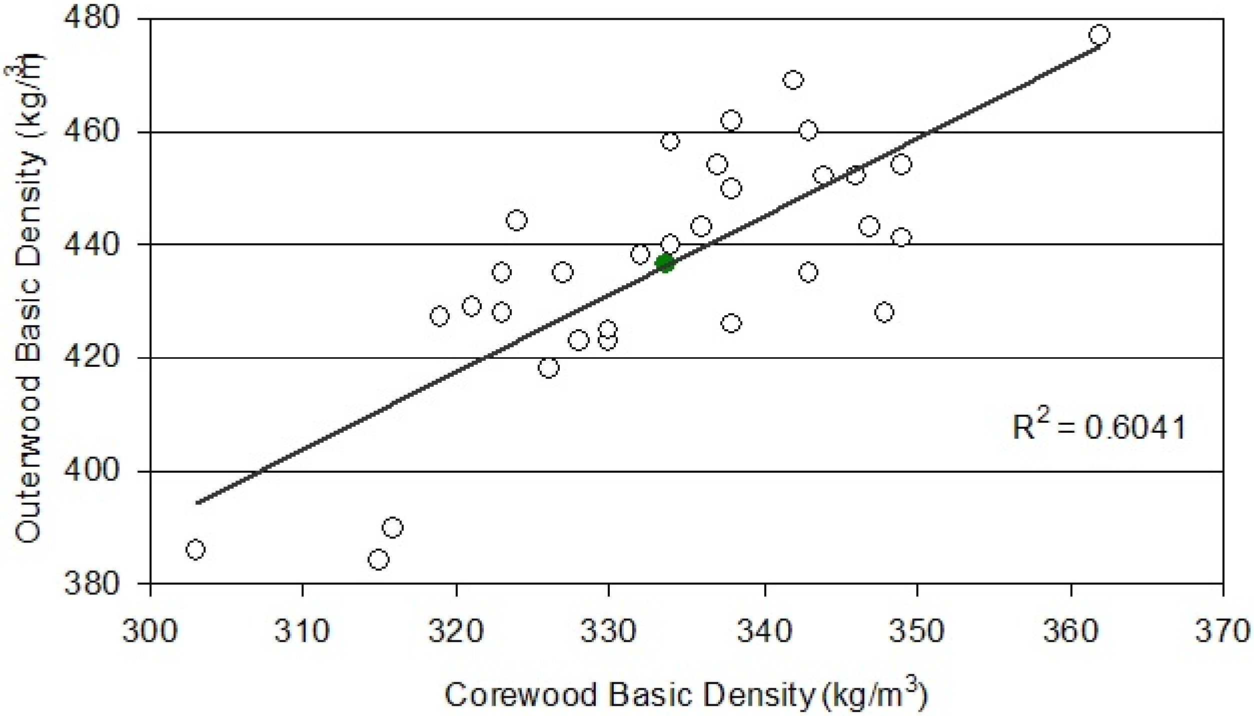

Figure 2. Relationship between corewood and outerwood basic density of improved *P. radiata* families.

Assessment costs can differ widely for different selection traits and this can have an important effect on a decision to invest in any particular trait. For example, diameter measurements at NZ$ 0.60/tree provide an inexpensive methods for estimating volume growth rate while wood density sampling at NZ$ 8/tree needs greater justification, yet is the preferred methods for estimating timber strength and stiffness. Clearly, R&D efforts aimed at improving both the range and cost-efficiency of assessment methods used in selection will be of substantial benefit in tree breeding programs.

Clonal Forestry

Benefits The benefits of clonal forestry have been cited for many years (Libby 1983; Libby and Rauter 1984; Carson 1986b) but have been slow to be implemented with conifers. The main benefits of clonal forestry include: 1) greater gains arising from testing and selecting clones, 2) clone/site matching to increase genetic gains both from capture of favorable G X E effects and targeting expression to existing site propensities, 3) greater uniformity which may have little impact on growth and yield traits but could be extremely valuable for log and wood quality and disease resistance traits, and 4) greater repeatability which can bring benefits in yield prediction and planning.

Cloning technologies Both hedging and serial propagation are nursery techniques that provide, in combination, one method for practicing clonal forestry (Libby and Hood 1976; Haines and Walker 1996). Hedging and the production of rooted cuttings are being successfully used on a large scale by the Queensland Department Primary Industries Forestry program in producing the *Pinus caribaea* X *Pinus elliottii* hybrid (Haines and Walker 1996). Tissue culture or micropropagation, using organogenesis methods, has been developed since the 1970's for mass propagation of conifers (Reilly and Washer 1977). In clonal forestry programs, organogenesis is used in *P. radiata* both as a mass propagation method as well as a clonal storage system (Menzies and Aimers-Halliday 1997) in combination with further multiplication using rooted cuttings.

Somatic embryogenesis is a recently developed technology that was first applied to forest tree species in the mid 1980's (Percy *et al.* 2000). Somatic embryogenesis can be used as an *in vitro* clonal storage method only, but it also has applications for propagation and has attracted interest due to the very high clonal multiplication rates that can be achieved (Smith *et al*. 1994; Menzies and Aimers-Halliday 1997). Clonal forestry using somatic embryogenesis is being successfully introduced on a commercial scale for *Pinus taeda* and *P. radiata* by CellFor Inc. (Sutton and Polonenko 1999).

Targeted Deployment of Improved Plants Site differences influencing gene expression can be turned into positive effects which can act to enhance the goals of tree improvement. For example, average wood density can vary predictably by as much as 100 kg/m^3 between different NZ sites. Since it has taken a 20-year breeding generation to achieve genetic gains of 25–30 kg/m^3 in average wood density of improved radiata pine in NZ, it is easy to see the value of the addition of these breeding gains to: 1) increase yields of valuable engineering timber grades on high-density sites, and 2) raise the limiting threshold for structural timber grades on low-density sites.

Similarly, the distance between branch whorls (internodal length) at different NZ sites causes the available length of clearcuttings timber grades (> 0.6 m in length) to vary from approximately 0.2 to 0.5 m in an average 5 m log, with resulting high gains in terms of financial returns to growers and processors (Carson 1988). Improved families of radiata pine can differ in similar magnitude, thus allowing these effects to also become additive providing further choices for growers in matching genotypes to sites to enhance profitability. As breeding work continues with more intensive improvement of wood quality traits, we expect that similar site/genotype matching gains will become available.

Biotechnology Applications The great potential for intensifying tree improvement through use of DNA-based biotechnologies has been regularly cited, yet such applications have had little commercial application to date (Carson *et al*. 1996). DNA fingerprinting is now in full commercial use in many tree improvement programs. However, due to highly adverse public perceptions, the use of gene transformation in forestry seems to be currently out of favour, despite continuing improvement of methods. The current emphasis in many forest research organizations appears to be focusing on two main areas: 1) attempting to clarify the risk factors (e.g., gene silencing, horizontal gene transfer) associated with transformation, and 2) attempting to better understand gene expression and function, leading to identification of biosynthetic pathways, and identifying ‘candidate genes’ for marker-assisted selection.

These approaches should lead to substantial benefits for intensive forestry, but commercial-scale applications would appear to be 10–15 years away. Marker-aided-selection (MAS) still has significant potential for immediate application and recent work combining the use of simulation methods with ‘proof-of-concept’ experiments looks very promising (S. Carson - 2 papers submitted to Forest Genetics). These studies assumed the existence of many small-sized QTL (Quantitative Trait Loci) in forest trees, and showed that gains from MAS can be comparable to those from conventional selection and be achieved in a much shorter time.

CONCLUSIONS

Although intensive tree breeding offers large benefits to plantation forestry worldwide, success will require inputs of time and dollars and a single-minded focus. Intensive tree breeding will be characterized by rapid changes in gene frequencies for favorable traits in the deployment population and, particularly with clonal forestry, will lead to more uniform forest crops with more predictable attributes. However, these benefits will not be easily won and will realistically occur only where plantation forestry is already profitable and is practiced on a large scale.

Is this compatible with sustainability? It is difficult to see any downside for sustainability as it applies to forest plantations benefitting from intensive tree breeding. The difficulties faced by many tree breeding programs can often be laid at the door of bureaucracies distracted by other issues and highly sensitized to public perceptions relating to the need to manage native forests in a responsible manner. Forest growers need to be able to continue to distinguish the financial goals of plantation forestry from those of conservation and to demonstrate that they can do more with less – that is, to show that high-yielding, high quality wood can be grown ‘for purpose’ on land deemed suitable for the growing of plantation crops. In return, it is to be hoped that government agencies will recognize that the benefits of applying a commercial business model to plantation forestry necessitate the *quid pro quo* of that business having the ‘freedom to operate’.

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FOREST CERTIFICATION, TREE IMPROVEMENT AND THE INFLUENCES OF MARKET-BASED PRESSURE ON FOREST MANAGEMENT

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INTRODUCTION

In the closing decade of the 20th century the forest industry has found itself stuck between two visions of its global role. The first believes the forest industry, being reliant on one of the world's few truly renewable resources, should continue to harness it in order to satisfy expanding societal demand for forest products. The second believes the forest industry, while relying on a renewable resource, is taking too much, leaving forest ecosystems damaged and unable to sustain their functions into the future. While this dichotomy is over simplistic, ignoring the numerous details of these visions,[1] it does serve to illustrate that tensions over what to do with the world's forests have and will continue to affect the types of management practices societies deem appropriate. Broadly speaking, acceptable management intensity will remain a core issue. For instance forest plantations, while affording a greater per hectare supply of wood fibre also have their environmental consequences. Therefore, decisions regarding the stand and landscape level role of plantations are paramount for local and global trends in both forest health and wood supply. Of course, tree improvement as a management tool is not shielded from these tensions; policy decisions regarding appropriate management intensity that favour one or the other of the dichotomous positions mentioned, will shape the future of tree improvement applications.

The recent development of forest certification is a perfect case for exploring these debates. Supporters of certification, many of whom have been key participants in the development of the various programs' respective standards, have notably disparate views on which forest management practices are appropriate. Tree improvement is one among a number of management tools under scrutiny. The benefits of increased growth rate in forest plantations to offset further losses of natural forests, the development of disease resistant species varieties, and the potential manufacturing efficiencies achieved through altering wood properties, are gaining recognition, yet not all stakeholders are willing to embrace these technological innovations, particularly in relation to their use in certified forests. This leaves unresolved, questions such as: What is the appropriate role of tree improvement in certified natural and plantation forest? Should the use of genetically modified organisms be permissible?

These questions form the focus of this paper. They are inherently political and as recent trends indicate, the market through the development of certification is becoming a strong force influencing the answers. In this regard, we shall illustrate how, increasingly, market pressure is coming in two forms, a first that places upward pressure on environmental standards (for instance market boycott campaigns), what we call green pressure, and a second that puts pressure on companies to cut costs in order to remain competitive (for instance increasing global capacity or the development of fast growing tropical and temperate plantations), what we call cost pressure.[2] Understanding these two forms of pressure is important for it helps us clarify the influence

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[1] Elaboration on the elements of this dichotomy can be found in works such as Aplet *et al.* 1993 and Lee 1991.
[2] Vogel (1995) refers to these as the "California" and "Delaware" effects, respectively. Other work that focuses on the upward and downward effects of market pressure include Paget and Morton 1999 and Bernstein and Cashore 2000.

certification might have on forest management broadly and tree breeding specifically.[3] The influence of both these pressures on tree improvement hinges largely on the degree to which green pressure wins out relative to the cost pressure. As we shall show, the fact that green pressure supports one particular form of certification, the Forest Stewardship Council, means the balance between the market pressures has the potential to significantly affect future developments in tree improvement practice and technology.

Thus, more than ever before, the market is directly affecting the ability of Canadian companies to compete and also indirectly impacting the amount and focus of research on tree improvement and biotechnology. It is our intention to explore these issues and we do so by proceeding in three parts. First, we review the history of certification and describe its current status in Canada and abroad. Particular attention is placed on the development of the different certification initiatives, the area of land certified, and the emergence and current status of green market pressure. Second, our attention shifts to the impacts of certification on tree improvement; the specific provisions certification standards use to assess the management of forest genetic resources. Variation is shown to exist in how genetics is addressed by the different initiatives and the degree to which these restrict tree breeding, and biotechnology use and research. Third, we offer thoughts directed toward future developments in certification. Our attention focuses on exploring two factors (institution and environmental policy problem characteristics) that will condition the degree to which certification affects tree improvement practices. Our conclusion outlines three points gleaned from our research that the tree improvement community would be well served to keep in mind.

FOREST CERTIFICATION

History and Development

Extensive work has been done documenting the development of certification and its origins (e.g.Viana *et al*. 1996; Elliott 1999; Vogt *et al*. 1999; Cashore *et al*. 2002). Here it will suffice to say that certification emerged due in large part to three factors: 1) the inability of governments to resolve forest management problems at the international level before, during, and after the 1992 Earth Summit, 2) a recognition that boycotts of tropical forest products were not effective at alleviating pressure on endangered forests, and 3) many forest products were entering the market place with false claims about the sustainability of their sources (Read 1994; Cabarle 1995).

At the international level, one significant outcome of these factors was the development of the Forest Stewardship Council (FSC).[4] The FSC was designed as an international body; it was mandated to pursue a list of 10 activities, all with focus towards promoting and encouraging improved management of the world's forests. The three main activities from this broad list were: 1) to manage the development of national initiatives and these initiative's efforts to develop regional standards interpreting the FSC principles and criteria (P&C), 2) to set up and manage a voluntary accreditation program to promote the P&C, and 3) to promote awareness about the importance of improved forest management through education (Forest Stewardship Council 2000b).[5]

During this period and in part as a response to the FSC, a number of national certification initiatives emerged. In Canada, a coalition of industry representatives formed in 1993 and approached the Canadian Standards Association (CSA) in 1994 asking the organization to facilitate the development of a national certification system for Canada (Abusow and Rotherham 1998). The CSA completed its work in 1996 with its release of a specification document (CAN/CSA-Z808) and a guidance document (CAN/CSA-Z809) outlining the parameters of the National CSA sustainable forest management system. The system drew on the Canadian Council Forest Management (CCFM) criteria and indicators as its basis.

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[3] Green market pressure has become an increasingly common phenomenon in the global forest sector (Hayward 1998; Bernstein and Cashore 2000). At the same time cost pressure through increasing global competition, over capacity in global markets and other factors, is placing pressure on companies to cut costs and rationalize their operations.

[4] While in the US, a number of certification programs were active before the FSC officially established in 1993, such as the Rainforest Alliance Smart Wood program and the Scientific Certification System Forest Conservation program, they willingly took part in the FSC and sought accreditation from the organization after its official formation (Ozanne and Vlosky 1996).

[5] Once more national standards are endorsed, the FSC will need to spend less time directly managing these processes. Further, in the future, some observers have noted that accreditation will become an independent operation. This theoretically will leave the FSC more time to manage the FSC label; maintaining the labels' integrity is speculated to become a serious issue for the organization's future credibility.

Outside Canada, alternative certification programs developed early in the U.S. and then later in Europe. In 1994, the American Forest and Paper Association (AF&PA) launched its Sustainable Forestry Initiative (SFI), which first began as an industry code of conduct but soon evolved into a program akin to a certification initiative (Meridian Institute 2001). By 1996 the initiative and its standards were made requirements to which all AF&PA members had to adhere.[6] Three years later in Europe, after many failed attempts by national forest sectors to develop market credible certification initiatives (Cashore *et al*. 2001), private landowners got together to develop the Pan European Forest Certification (PEFC) initiative (Hansen *et al*. 1999). Unlike the SFI and CSA, the PEFC developed as an umbrella organization providing a framework for mutual recognition of independent national certification initiatives (Table 1).

One significant point that distinguishes these initiatives is their respective approaches to certifying sustainable forest management. They consequently occupy different positions in relation to the dichotomy we introduced above. On most substantive policy issues, the FSC tends to be more prescriptive, while the SFI, CSA, and PEFC leave a greater degree of discretion to forest managers (Bass *et al*. 2001; Ozinga 2001). The points on which the FSC restricts forest practices make the initiative align more with those who feel current practice is unsustainable, regardless of the inherent renewable nature of the resource. This is a significant point to keep in mind as we proceed to discuss the global market interest in certification and the way in which all four of the certification initiatives address the management of forest genetic resources and the use of tree breeding and biotechnology.

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[6] Predating the SFI in the U.S. there was the American Tree Farm system, an initiative established in 1941 to encourage sustained yield management of non-industrial private forests (Coulombe and Brown 1999). Recently, the Tree Farm system has been updated with an expanded set of standards and requirements and in 2002 went through a national audit conducted by Pricewaterhouse Coopers that assessed the system's strengths and weaknesses. We do not review the Tree Farm system here as its standards are specifically designed for non-industrial forest owners in the U.S. Instead we review the PEFC, which overseas a number of national certification initiatives designed for non-industrial forest owners.

Table1. Details on the initiatives commonly referenced in relation to the certification of forestlands

Features	CSA	FSC	PEFC	SFI
General description	Non-profit membership association	Non-profit membership association	Non-profit voluntary private sector initiative	Initiative conceived by American Forest and Paper Association. Available for members and non-members
Membership	Three types open to any individual: 1) Volunteer - vote on standards 2) Associate - no vote; contribute to committees 3) Sustaining - dues support standards work.	Individual and organizations. Split into three chambers with equal voting rights for representatives from Northern and Southern interests.	Composed of 19 national governing bodies. Forest landowner associations responsible for bringing together relevant national stakeholders to form national body.	Companies, associations, and individuals categorized as Company, Associations, Associate, or Designated professional members.
Governance	Board of Directors voted in by the members. Three branches: 1) CSA - standards development 2) CSA International - for product testing and certification 3) QMI - for management systems registration (other companies also accredited to certify with the CSA standard).	Governed by general assembly maade up of individual and organizational members. When acting collectively, assembly holds ultimate authority. Board of Directors formulates high-level policies, strategies, and plans and has controls over administrative functions.	Governed by general assembly comprised of one representative from each national member body. Assembly holds highest authority. Voting rights weighed by level of production in member country. Majority rules, unless otherwise directed.	Sustainable Forestry Board comprised of 60% non-industry interests. Oversee improvements to standard, certification process, and work with AF&PA to resolve non-compliance issues (i.e., quality control measures).
Role in certification	CSA - manages the development of standards and procedures for certification. CSA International - provides access to the CSA mark.	Controls the international FSC principles and criteria (P&C). Accredits companies and organizations to certify against FSC P&C. Supports and regulates the development of national specifications of the P&C (i.e., the development of national indicators and verifiers).	Offers an international framework for forest certification schemes and initiatives. Sets requirements for members who want their national forest certification scheme/initiative endorsed by the PEFC.	Sets program structure and procedures for companies implementing the SFI. Sets standard requirements and guidance for program participants.

Sources: Table 2 in Auld *et al.* (2002). For more information refer to the following websites:
http://www.pefc.org, http://www.fscoax.org/principal.htm, http://www.afandpa.org, and http://www.csagroup.org

Area Certified

The area certified under all certification initiatives remains small on a global scale (Figure 1). Approximately 100 million hectares have received certification under the FSC, SFI, CSA, or PEFC forest certification initiatives, which represents approximately 3% of the world's total forest area (3.87 billion ha) or close to 6% of the forest area (1.60 billion ha) that has already been disturbed by humans (FAO 2001b).[7]

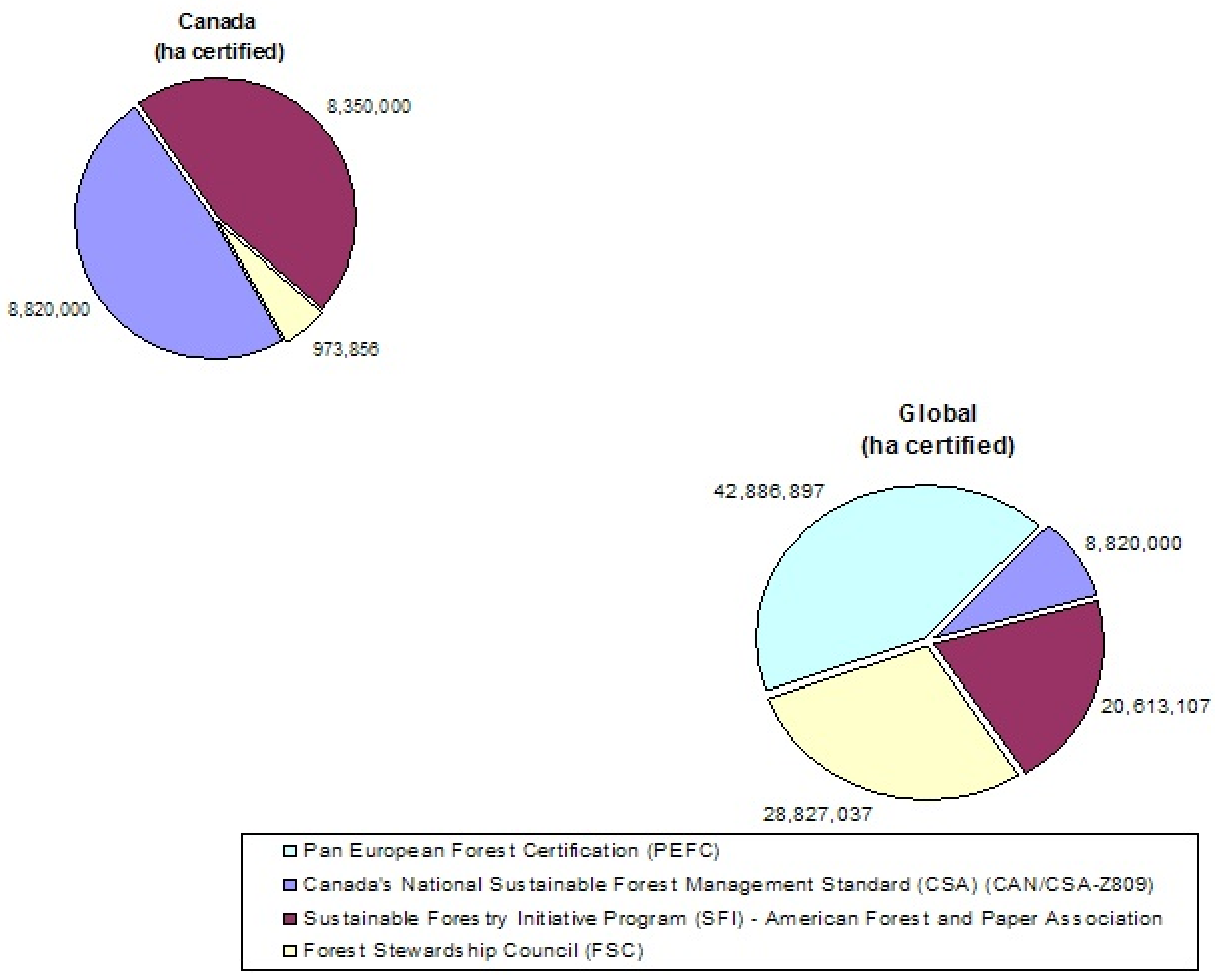

Figure 1. Canadian and Global forestland in hectares certified with the FSC, CSA, SFI, and PEFC.

Sources: (Forest Stewardship Council 2000a; Abusow 2002; American Forest and Paper Association 2002c; Pan European Forest Certification Council 2002).
Notes: Certified areas for the SFI only include forestland that has undergone third party certification.

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[7] The global figures over-estimate the total certified area, as they do not account for overlaps among the certification initiatives. Some companies have received certification under more than one initiative, meaning some area has been double counted. The discrepancy between the area reported here and that reported in Atyi and Simula (2002) is explained by the exclusion of forestlands certified under the American Tree Farm system. This accounts for approximately 10 million ha.

Markets for Certification

On the market side, growth has been more extensive and asymmetric. In most cases the FSC remains the program of choice. While in the US the SFI claims an increasing number of companies are opting for products with SFI certification (American Forest and Paper Association 2002b), major retailers, such as Home Depot remain supporters of the FSC. Furthermore, the Global Forest and Trade Network (GFTN), an international network of producer and buyer groups promoting the production and purchase of FSC or equivalent certification, continues to expand with increasing numbers of individual company participants and national network members (Figure 2). As of 2002, membership expanded to include nearly 700 companies operating in 20 countries.[8] Many of these countries represent key consuming markets for forest products. For instance, in 2000, the U.S. market was estimated to consume approximately 530 million cubic metres round wood equivalent.[9] European markets, where FSC demand is strong, such as Germany and the United Kingdom, also represent significant consumers of forest products. In 2000, Germany was estimated to consume 56 million cubic metres round wood equivalent and the United Kingdom 52 million. Within these three markets, and with the addition of Canada, there are 344 organizations that are participating members in the GFTN (Global Forest and Trade Network 2002).

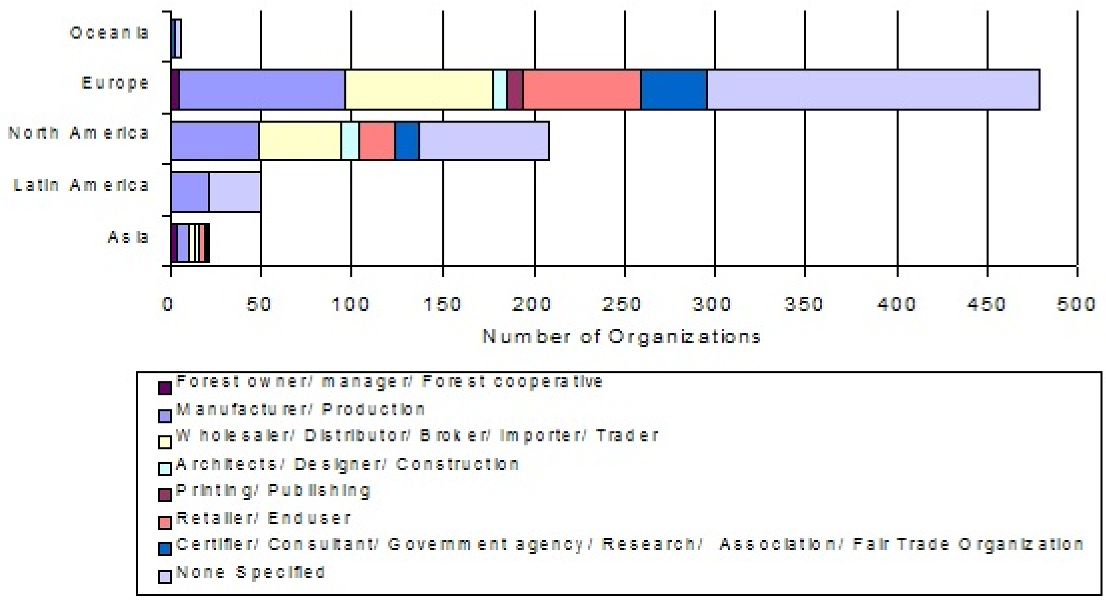

Figure 2. Profile of the Global Forest and Trade Network.

Source: (Global Forest and Trade Network 2002)

Not only is the FSC gaining support from large companies at the customer end of the supply chain, but also efforts in Europe to bolster the recognition of the FSC amongst the general public (the end consumer) are reported to be proceeding in leaps and bounds. In the United Kingdom and the Netherlands the proportion of the general public able to identify the FSC logo has reached double digits.[10] This points to a growth in FSC market in Europe that will likely have lasting effects on global forest product markets, as green pressure from consuming companies in Europe push the FSC towards being an industry-wide standard. However, whether this occurs is still moot given the FSC market share in Europe is reported as a mere 5% (Atyi and Simula

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[8] Since these figures were published by the GFTN, the Central American Buyers' group was added, expanding the total number of participating countries to nearly 30.

[9] Information obtained from James Hewitt. Conversion factors for calculating round wood equivalency can be obtained at the following web page http://202.78.129.207/statistics/primaryindustries/forestry/nzstats2000/appendix/append4.htm

[10] Justin Stead 2002. Personal Communication.

2002).[11] The extent to which slow adoption and, in certain cases, staunch opposition to the FSC will diminish these effects is still uncertain. With this information as a backdrop, let us proceed to explore how genetics fits in this picture. How do the certification initiatives treat forest genetics, tree improvement, and biotechnology use and research?

Certification Standards

As we indicated above, FSC standards are more prescriptive than those of the CSA, SFI, or PEFC initiatives. This is no different when we look at standards pertaining to forest genetics. The FSC is the only initiative that bans the use of genetically modified organisms (GMOs) (stated in Criterion 6.8 of its P&C) and states a strong preference for silviculture treatments that promote natural regeneration. Artificial regeneration is permissible, but only when seed or vegetative planting material is produced from local provenances (stated in Criterion 6.3b of the P&C). In addition, the FSC also sets standards for plantation management. Plantations are only acceptable given the premise that their inclusion in a management unit facilitates the protection, restoration, and conservation of natural forests.[12] Regional standards processes are given the discretion to set thresholds for how much of the forest management area under plantation management must be restored to natural forest cover (Forest Stewardship Council 2001).[13] Management occurring in these areas is encouraged to consider genetic diversity in the context of ensuring economic, ecological, and social stability (stated in Criterion 10.3 of the P&C). Again, encouragement is given to the selection of seed or vegetative material coming from local provenances (stated in Criteria 10.4 of the P&C) (Forest Stewardship Council 1999b).

Beyond this, however, no thresholds are set in the FSC P&C that speak directly to the management, protection, or conservation of forest genetic resources. More specific requirements are left to the discretion of regional and national working groups creating standards for their particular forests. In British Columbia (BC) for instance, the FSC BC third draft standard sets thresholds for the retention of dominant and co-dominant trees and snags measured in both stems per ha and basal area (m^2/ha) (stated in the FSC BC Indicators 6.3.9- 6.3.11) (Forest Stewardship Council 2002b).[14] However, thresholds are not set for effective population sizes for planted seedlings grown from orchards or obtained from collected seed or vegetative material. As well, there are no specific measures for how to assess the adaptability of planting stock to a given site or the extent to which retention trees capture the range of natural genetic variability in an area.

The other three initiatives use standards that make few normative assertions about what silviculture treatments managers can or cannot use. Canada's National Sustainable Forest Management Standard (CAN/CSA-Z809) requires the conservation of biological diversity, of which genetic diversity is a part, and is to be addressed by conserving the variation of genes within a species (stated in Criterion 1, Critical Element C of the CCFM standard). Further specificity on how to achieve this is left to the discretion of the company seeking certification; companies are required to develop at least one local level indicator and associated targets (thresholds or limits) for each critical element and must do so in consultation with local stakeholders (Canadian Standards Association 2002). Comprehensive requirements are set for the public consultation process, however, there is no clear standard on what indicators and targets or limits are appropriate for conserving genetic diversity.

For the SFI, the program is clear on the purpose of managing forest genetic resources. The use of tree improvement and biotechnology are viewed as beneficial given they can increase the growth potential (productivity) of a given stand. Under two of the SFI performance measures the emphasis is on adhering to scientifically sound methods and legal protocols for tree improvement and biotechnology practices (stated in Performance measure 4.1.2.1.6 of the SFI standard) and selecting planting stock well adapted to the local conditions (stated in Performance measure 4.1.2.1.1 of the SFI standard). Both natural and artificial

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[11] According to Vilhinen *et al.* 2001 of this 5%, the majority is demand for FSC certified wood (67%).

[12] The FSC Principle 10 states, "While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressure on, and promote the restoration and conservation of natural forests (Forest Stewardship Council 1999b)." Virtually all of the Criteria associated with Principle 10 emphasize the protection, restoration, and conservation of natural forests.

[13] In the third FSC-BC draft standard, for instance the standard requires no more than 10% of the timber harvesting landbase be under plantation management (Indicator 10.5.1). If an operation exceeds this threshold, they will be issued a failed assessment on all of Principle 10 (Forest Stewardship Council 2002b).

[14] The FSC BC Draft Three was submitted to FSC for formal endorsement on June 13, 2002 (www.fsc-bc.org/showpage.asp?pageid=348&menu=13). It was sent to FSC having received a 7 to 1 vote in its favour in BC and a 5 to 1 vote in its favour with one abstention in Canada. Representatives of the economic chamber cast all three non-affirmative votes (McDonell 2002).

regeneration is permissible, but time constraints of 2 years for artificial and 5 years for natural regeneration are in place for how long reforestation efforts are to take (stated in Performance measure 4.1.2.1.1 of its standard) (American Forest and Paper Association 2002a).[15]

Finally, the PEFC addresses genetics in its Criteria and Indicators as well as Operational Level Guidelines. Both come from the Pan European Process on Forests that took place in Helsinki and then Lisbon (Pan European Forest Certification 2001b). Neither, however, are set as requirements to which national initiatives must adhere, rather they establish the baseline for what PEFC forest management will look like. Indicators promote the development of institutions supporting the conservation of genetic diversity and the application of appropriate monitoring of trends through time to ensure change in genetic resources is recognized. The guidance document goes further promoting the use of natural regeneration and local provenances when planting is required (Pan European Forest Certification 2001c). Beyond this, little is specified. National initiatives that seek recognition by the PEFC system must make their own specific national standards that address these broad objectives. Overall, however, silviculture treatments including traditional tree improvement techniques and biotechnology receive limited direct attention.[16]

Table 2 summarizes the approaches taken to address genetics by the four respective certification initiatives. The FSC places the greatest emphasis on natural processes, presuming that natural patterns and avoidance of technologies such as genetic modification techniques will best serve interests in maintaining the future integrity of forest ecosystems. Standards on planting stock selection, plantation management, and biotechnology align with this cautious position. The PEFC, while sharing a certain commonality with the FSC in its emphasis on mimicking natural processes, follows more closely the flexible approach chosen by the CSA and SFI at the standards level. These initiatives set no substantive requirements in their standards that directly inhibit the use of traditional tree improvement or biotechnology; they rely instead on existing government regulations and standards to define appropriate practice.

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[15] Other SFI indicators under Performance measure 4.1.2.1.6 include “Monitoring gains in forest growth realized from investments in genetic tree improvement and update yield calculations,” and “Utilize seed collection areas and/or seed orchards to produce quality growing stock” (American Forest and Paper Association 2002a). Both these illustrate the SFI focus on using tree improvement to increase the growth of forest stands.

[16] The French PEFC National Initiative acts as the exception on the biotechnology issue. Under its standard genetically modified organisms are only permissible when local stakeholders can agree to the terms of their use (Pan European Forest Certification 2001a).

Table 2. Attention given to genetics by four main certification initiatives.

FSC	CSA	SFI	PEFC
Variable and vague. Promoted natural regeneration for maintaining genetic diversity. Documentation on seed source and clear rationale for actions that affect genetics on a given site. Greater emphasis on maintaining natural functions, meaning genetics addressed along with other forest conditions. Ban on the use of GMOs.	Vary between companies. Emphasize the conservation of genetic diversity as a part of biological diversity. Genetics issues developed and are dealt with on a company by company basis.	Vary between companies. Emphasis on protecting genetic resources as a source of future improvements for forest productivity. No practices prohibited. Encourages practices that are scientifically based.	Vary between national initiatives. Promote natural regeneration and emphasize protecting natural forest function. Attention to genetics from very specific to non-existent.

Source: Table 2 in Auld 2002

This does not mean that the actual practices on the ground – such as the use of minimal effective populations and procedures for ensuring quality and well-adapted planting stock – will not be in place under any of the given initiatives. However, the prescriptive nature of the FSC and its presumption that certain silviculture treatments and technologies are not appropriate to apply in certified forests means the FSC will have a considerable effect on the direction of tree improvement practice and research in the coming years. That is, if the FSC is able to maintain its position as the most widely recognized certification logo in the market it will maintain its green pressure on forest management practices. These are issues we turn to now in our discussion of future trends in markets and political developments that will shape certification's effects on tree improvement practices.

CERTIFICATION'S IMPACTS ON TREE IMPROVEMENT

Two points are clear from the information just described. The first is that tree improvement as currently practiced is permissible under requirements of all certification initiatives, while differences exist in the acceptance of research on and commercial planting of GMOs.[17] In a recent research project that reviewed how well BC regulations, standards, and requirements pertaining to forest genetic resources would do given the various certification requirements specific to forest genetics, both interviews with environmental groups, forest geneticists, and industry officials and direct comparison between government and certification requirements indicated existing standards are robust (Auld *et al.* 2002). Nonetheless, the standards of the four certification initiatives do differ in substantive ways that indicate their future impact on tree improvement will diverge. For instance, current tree improvement practice may meet existing certification requirements, however targets such as the one set by the BC government promoting the planting of genetically improved seed combined with declining levels of natural regeneration may lead to conflict between management practice and certification requirements, particularly those set by the FSC.[18]

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[17] The FSC includes the following under its definition of traditional breeding techniques: "*in vitro* fertilization; conjugation, transduction, transformation or any other natural process; polypoidy induction; mutagenesis; and cell fusion (including protoplast fusion) of plant cells where the resultant organisms can also be produced by traditional breeding methods (Timothy 1999)."

[18] In 1992, 49% of the BC's harvested forests were managed for natural regeneration (Ministry of Forests Silviculture Interpretations Working Group 1992). By 1996 this level had dropped to 27% (Ministry of Forests 2000). If the trend towards artificial regeneration continues concerns may mount, especially if rates of natural regeneration infill fall. Conflict over the use of artificial regeneration will be exacerbated by the fact that the BC government has set a goal of 75% use of select seed in its reforestation efforts by the year 2007 (Anon. 2001).

The second, and not entirely unrelated point, is how forest plantations are regulated. This is especially important for the issue of wood supply and the preservation of natural forests. There are two differing perspectives on the matter. Under the FSC, plantations are deemed permissible, but it is stated that they should represent a minimal part of the total landscape, fit with landscape level biodiversity considerations, reduce pressure on natural forests, use least intensive management techniques (i.e., minimize and reduce potential hazards of chemical and exotic use and promote integrated pest management techniques), and consider social impacts of plantation design and structure (Forest Stewardship Council 1999b). For the other programs, restrictions explicit to plantations are not made.

This issue re-introduces the dichotomy we raised in the introduction to this paper and emphasizes how important the substantive elements of the standards are in shaping and defining appropriate forest management around the globe. As Victor and Ausubel (2000) noted, "Certification that [favors] low-yield strategies may produce a happy tree but lead to a small forest." In other words, if we continue to increase our consumption of wood, we will need to improve the per hectare yields of forests in order to meet demand and protect remaining areas of natural forests (Sedjo and Botkin 1997; Victor and Ausubel 2000). Lower yields mean a greater area of forest is needed to produce the same amount of forest products, given that trends in consumption remain the same.

The future use of GMOs is purported, by some to be a key way to achieve greater yields and thus alleviate pressure on natural forests (Sedjo 1999). However, on the issue of GMOs, clearly the FSC is remaining cautious, claiming that the science has not yet demonstrated that this technology is free of unacceptable risk (Timothy 1999). For the moment, this may be insignificant in its effects on current practice given limited GMO forestry applications (Owusu 1999; Sedjo 1999). However, in the future, the FSC policies that effect both commercial planting and field-based research, may stifle progress towards solutions to pest resistance problems, improvement of wood quality (such as reduced lignin content or increased wood density) and rates of growth.[19] Thus, depending on which initiative gains widespread support, in the absence of fundamental changes to their requirements, the effects on forest management will be quite different. We can see, therefore, that change largely hinges on 1) how resilient to change the FSC policy proves to be and 2) the degree to which green market pressure will remain supportive of the FSC. We address these two points below.

FSC Policy Change

Historical evidence is mixed on how prone to change the FSC is. On certain policy issues, such as percentage based claims (policy on amount of FSC certified wood required in products carrying FSC label), a number of policy iterations have occurred which have resulted in lower thresholds being set for how much FSC certified wood is needed in an FSC labelled product (Forest Stewardship Council 2000a).[20] On the GMO issue, however, it seems unlikely that change will occur in the near term for two reasons. First, the institutional structure of the FSC means policy decisions made on issues such as the ban on GMO use and research are made through a membership-wide voting process (Forest Stewardship Council 1999a). Given the serious concern over GMO use held by environmental groups such as Greenpeace,[21] who are voting members of the FSC, and general public sentiment against them that has taken root in Europe, it seems doubtful that the ban will change in the near term.[22] The time required to develop a revised policy, added to the need for membership endorsement, makes change unlikely.

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[19] On a related and extremely important point from the perspective of forest ecosystem integrity, it can be argued that standards that the FSC develops seriously limit its ability to gain support from the majority of industrial and non-industrial private forest owners, and public forest owners alike, limit the initiative's ability to achieve landscape level conservation objectives: objectives that are increasingly recognized as central to viable forest conservation (Rowe 1998).

[20] Initially, the FSC required 100% FSC certified wood content for solid wood products and 70% for products made from wood chips and fibre. It is now possible for solid wood products to carry the FSC label if, at least 70% of its content is from FSC certified wood. For chip and fibre products and components the requirement is a minimum of 30% FSC certified virgin fibre and 17.5% of the total fibre FSC certified (Forest Stewardship Council 2000a).

[21] Greenpeace has been vocal in its concerns about the use of GMOs in agriculture (Aken 1999; Greenpeace 2001), a position it has begun to articulate equally in forestry GMO applications (Mario Rautner 2002 Personal Communications).

[22] As Strauss *et al*. (2001a) noted: "Having a clear and simple green image, uncomplicated by GMOs with their diverse ecological and social complexities, is likely to be important for wide recognition – especially in the GMO-averse European market."

Second, forest management is complex and its impacts on forest ecosystems diverse and not well understood. The absence of agreement over the technical and scientific side of forest management makes it difficult to develop realistic and concrete commitments to achieving improved forest management (Victor and Ausubel 2000). This is exasperated by the ambiguity of many forest management goals (e.g., preserving biodiversity, or maintaining ecosystem integrity) that are also apt to change with shifts in societal values (Bunnell 1998).[23] This has led many policy makers and organizations to invoke the precautionary principle, which essentially promotes adopting cautious policies to environmental problems in the face of ill-defined science (Noss 1993).

The issue of biotechnology is no exception: precaution in the absence of established and accepted safeguards for GMO use is one of the justifications for the FSC ban. The FSC has been subject to significant criticism of this policy (Coventry 2001; Strauss *et al*. 2001a, 2001b). As Strauss *et al*. (2001a) argue, the FSC ban is counter-productive since it does not rationally address the real environmental benefits and costs of biotechnology and is inconsistent since it contradicts its own policies on the use of other silviculture treatments such as the application of chemical pesticides, traditional tree improvement, and the planting of exotics. These treatments, Strauss *et al*. (2001a) argue, can and often do have considerably more potential for negative impacts on forest ecosystems than does the use of GMOs.[24] But as Strauss *et al*. (2001a) even admit, it is easier to have an outright ban on GMOs than confront the complex social, economic, and ecological facets of this emerging technology, especially if the FSC is trying to maintain its green image with environmental groups and the concerned public. Again, this policy is open to change, however, given the just described institutional structure of the FSC, such a change will not be easy to achieve nor quick to occur.

Regardless of these institutional and technical barriers to change, the fact that current tree improvement practice seems acceptable to the certification initiatives, the arguments over the appropriate use of GMOs does not appear too important. Further, because many of the most intensively managed plantations in the world, where intensive breeding programs are in place, have already been certified under the FSC,[25] it will become increasingly difficult for the FSC to justify significantly more strict standards in regions such as BC, given pressures for standards that provide a reasonably level playing field. Furthermore, the FSC has not yet been successful in establishing itself as the only certification initiative gaining the interest and support of the global forest industry. Given the evidence that the CSA, SFI, and PEFC provide companies with more discretion in the standards used for a certification audit, such as no restrictions on the use of GMOs beyond government regulations, certification may have a very limited effect on tree improvement and the future use of or research into biotechnology applications for forestry. In this way, the green pressure that is presently backing the FSC, will not be effective in altering forest management practices and shifting it towards the end of the dichotomy we raised that promotes reduced forestry activity, but in the absence of reduced consumption, will lead to a greater area of forest being utilized for production. We now turn to exploring this final and very important issue: the extent to which green pressure will affect tree improvement practices.

Green Market Pressure

Green market pressures have been a constant driving force behind the development of certification. This could lead one to conclude that the FSC, given its greater support in the market place, has the upper hand, however, as the previous discussion illuminated, the FSC standards restrict forest practices more so than any of the other initiatives. The balance between cost and green market pressure, therefore, are extremely

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[23] Much of this stems from the absence of agreed upon terminology of such basic terms as biodiversity. As Delong (1996) noted, "Although conservation cannot be put on hold until a definition of biodiversity is agreed upon, a widely accepted fundamental definition of biodiversity is imperative for effective communication and cooperation within and among different countries, government agencies, disciplines, organizations, and private landowners… If entities in the planning process view biodiversity in fundamentally different ways, agreement on management objectives and strategies for biodiversity conservation could be impaired."

[24] For the case of exotics, Strauss *et al*. (2001a) argue that "Compared to invasive tree species – which impose a complex array of novel traits and their thousands of underlying novel genetic interactions into an ecosystem – the ecological alterations from transgenes are obviously very limited."

[25] Fletcher Challenge Forests Limited manages a 360 000 ha forest estate in New Zealand. The estate is located on the Central North Island. Seventy-eight percent (i.e., 282 300 ha) of the forests are managed under a plantation regime with 91% being planted with radiata pine, 7% with Douglas-fir, and 2% with eucalyptus (Fletcher Challenge Forests 2001). Scientific Certification Systems certified the Company's lands to the FSC standard in 2000 (Scientific Certification Systems 2000). South Africa, Brazil, Sweden, and Indonesia are other countries where large areas of plantation forests have achieved FSC certification (Forest Stewardship Council 2001a). Currently, Principle 10 is undergoing review as a direct result of the debates over the role of plantations in certified forests (World Wildlife Fund 2002).

important in affecting the decisions of which certification initiative will become dominant if any at all.

In the second section of this paper we described the growth of the GFTN and the expanding market recognition of the FSC in Europe. In Europe, adoption of FSC certification is becoming more extensive with significant areas of land achieving certification in the United Kingdom, Sweden, Estonia, Latvia, and Poland.[26] Tensions still exist between the PEFC and the FSC, however, inroads are being made. For instance, in Sweden work is underway on *Forest Dove* a bridging document that aims to clarify what PEFC certified forest owners will need to do to obtain FSC certification and vice versa (World Wildlife Fund 2002). In Germany, where landowner opposition to the FSC remains widespread (Cashore *et al*. 2001), some public forests are applying to obtain FSC certification noting that demand for FSC is exceeding supply (World Wildlife Fund 2002). Some officials involved in certification in Europe are of the opinion that the FSC is beginning to look like an industry wide standard.

In North America, the picture is quite different. While companies like Western Forest Products in BC and J.D. Irving, Limited in New Brunswick took an early interest in the FSC, these companies' respective attempts to achieve certification were mired in controversy and conflict (Zammuto *et al*. 1998; Lawson and Cashore 2001). Neither currently has FSC certification in Canada despite having both started down the certification road more than 5 years ago. South of the border, the situation is similar. None of the major forest products companies have pursued FSC certification, however, this has been more the result of conscious choice rather than the result of political struggles, as seen in Canada. Nevertheless, the impact of this is such that the FSC has become more of a niche market in the U.S. even though large retail companies such as Home Depot are expressing an interest in FSC products.

So what does this mean for Canadian producers and the tree improvement community? In the U.S. it is apparent that the AF&PA, given that its membership control a large proportion of the domestic forest market, has been able to keep the FSC out of the mainstream (Cashore *et al*. 2001). The SFI has recognized the importance of starving the FSC of market share to the extent that it has pursued policies permitting Canadian companies to join the program through a Licensee program (American Forest and Paper Association 1999, 2000).

We can therefore speculate that there is actually an opportunity for Canadian companies to take advantage of the relative absence of FSC certification in the U.S. In fact considering the certification standards relevant to tree improvement, arguably, it might be in the interest of Canadian companies to pursue FSC certification given: 1) the use of GMOs is not commercially viable in the majority of Canada's forests at present and 2) other restrictions on forest practices could be offset by gaining access to FSC markets in the U.S. Further, the FSC only restricts GMO research in forests that are FSC certified (Timothy 1999). If the Canadian industry and government could agree to areas where research were to take place, it seems very possible, that the FSC GMO policy would have very limited impacts on the certification of Canadian companies.[27]

Certainly, a widespread move by Canadian companies to pursue FSC certification would not be viewed favourably by supporters of the SFI within the U.S.,[28] yet Canadian companies have no particular political reasons why they should not take advantage of FSC demand in the U.S. market. This said, many other factors are at play in making such a vision somewhat unrealistic. For instance, there are many other components of the FSC standards that will undoubtedly increase costs and offset any benefit possibly available from meeting U.S. demand for FSC wood. In any event, in the near-term, tree improvement will remain an important forest management tool that will play a role in certified and sustainably managed forests. Questions surrounding its future role, will likely be decided by a combination of rigorous scientific analysis and political decisions that, given certification, are likely to be, if not decided in the market place, at least notably influenced by market pressures. The balance between green pressure and cost pressure is gaining ground as the new arbiter of policy choice (Cashore 2002) and will likely effect the extent to which future forestry practices more closely

[26] Combined, these countries have 17 158 167 ha of forestlands FSC certified (Forest Stewardship Council 2002a).

[27] In BC, for instance, the government has outlined, in a number ways, that existing standards would not permit GMO use on Crown lands. Further, a 10-year moratorium on planting GMOs was suggested by the Forest Genetics Council of B.C. (Auld *et al.* 2002).

[28] This is especially the case due to the share Canada holds of certain U.S. markets: Canadian exports of softwood lumber to the U.S. reached over 18 billion board feet in 1999 (Council of Forest Industries 2001), which represented approximately half of the total U.S. production for the same year (36.5 billion board feet) (Warren 2001). General conifer sawnwood exports from Canada to the U.S. in 1999 represented approximately 50% of U.S. apparent consumption of this product class (FAO 2001a). This indicates that ample opportunities exist for Canadian companies to satisfy FSC demand in the U.S. being left unfilled by U.S. producers.

resemble the interests of either one of the dichotomous views we outlined at the inception of this paper.

CONCLUSIONS

The dichotomy we outlined describes the polar extremes of numerous societal impressions of forest resources and their appropriate use. By doing so we ignored the subtle elements of these views and the many individuals that find themselves caught in the middle. Nonetheless, this simplification facilitates a better understanding of how the underlying values guiding those concerned about the world's forests allow them to foresee quite distinct futures for forest management. This helps to clarify the importance of broad policy choices and global green market trends given their potential to affect tree-improvement practices. It affirms that the tree improvement community must be aware of international trends if they are to gage how the broad forestry community will view future tree improvement practice and research activities, especially those pertaining to and using biotechnology.

A second and related point, is that certification seems to be here to stay; however, which initiative will dominate and in what form remains moot. We touched on how the balance of cost and green market pressure acts as an important factor in determining certification's success or failure. This is a particularly important point as it can be argued that the market is becoming the venue in which, increasingly, forest policy choices are being made. Depending on which initiative gains green support will in part determine the extent to which management practice changes. If the FSC wins out, the effects on tree improvement, given existing draft regional standards, are not likely to be dramatic in the near-term. However, the policy banning research into GMOs and the prospect that increased use of select seed for planting in the absence of sufficient natural regeneration, will pose hurdles in the future. The other initiatives, given their present standards, provide no such limitations. Of course, all certification initiatives are designed to change, which also effects how much certification will impact tree improvement practices. We illustrated how the FSC is generally resilient to change due to its institutional structure, and unlikely to change on the GMO policy issue due to: 1) the technical uncertainties of GMO use and research and 2) the ambiguous character of forest management goals. This indicates that if the FSC can maintain support from the market, as it has been more successful doing in Europe, it will likely pose challenges to developments in tree improvement in the longer-term.

Finally, none of the certification initiatives, or the broader community of Criteria and Indicator processes seem well tooled to measure the on-the-ground appropriateness of management practices affecting forest genetic resources. For genetics, there is a clear need to develop simple protocols for assessing appropriate management, such that forest genetic resources are well maintained. Bridging the gap between science and policy has never proven easy, as the grey area between the two is characteristically ripe with conflict. As is often recognized, taking the step into the political realm brings to question science's objectivity: the scientist turns from value-neutral observer to political advocate. The challenge for the tree improvement research community is to maintain its arms length status, while simultaneously providing technically relevant information to certification initiatives and others involved in developing standards for sustainable forest management. The legitimacy and authority of this information will hinge on the apparent separation it can maintain from the interest-based struggles that situate themselves in discussions over what is sustainable. This is a challenging path to follow, but if tread carefully, it has the potential to greatly assist global efforts to improve our understanding and management of the world's forests.

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VOLUNTEER PAPER ABSTRACTS

“POPLAR SILVICULTURE”

FOREST 2020
A CONCEPT – AND A DIALOGUE – WHOSE TIME HAS COME

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How will Canada respond to domestic and international pressures to further the conservation of forest ecosystems, as well as ensure the forest sector's economic prosperity and well being of resource communities?

In 1999, the Canadian Council of Forest Ministers (CCFM) began discussing how Canada's forest sector might address these value-laden trends over the next two decades and mandated a Task Force to develop a common vision for forestry in the year 2020.

The innovative approach proposed by the Task Force, called Forest 2020, aims to increase the conservation value of forests and community benefits from all forest resources while ensuring the continued growth of the forest industry. All forestry jurisdictions in Canada have agreed to work together to develop it, recognising that the implementation of Forest 2020 would likely vary from region to region. Ministers committed to open a dialogue with Canadians and key stakeholders in further defining this approach. This dialogue began in April 2001.

There has been genuine interest in going forward to better define this initiative through an open and transparent process. At their September 2001 meeting, CCFM Ministers endorsed principles based on the initial dialogue to guide the development of Forest 2020 and from those principles a Vision Statement was developed.

The concept of a varied and flexible approach involving fast growing, high-yield plantations is garnering more and more attention across Canada as a possible means to increase wood fibre supply from the finite land base, while promoting innovation. As all three dimensions of Forest 2020, fibre production, forest conservation, and community well being are inseparable, the subject of how to integrate them in practice calls for informed and constructive debate. Discussions will continue throughout 2002 and are crucial in defining conditions and practical approaches to realizing the Forest 2020 vision.

RECLAMATION OF ROADS AND LANDINGS WITH UNROOTED NATIVE BALSAM POPLAR CUTTINGS IN NORTHERN ALBERTA

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Balsam poplar (*Populus balsamifera* L.) cuttings are relatively inexpensive to produce and plant and could be used to reforest marginal areas where natural stocking is often inadequate, such as on abandoned roads and landings, or in-block failures. In the first part of this study, we tested different combinations of pre-planting treatments (soaking, rooting hormones, and season of collection) on hardwood cuttings from a selected superior clone versus cuttings from randomly selected trees, planted in a greenhouse. Secondly, we tested survival and early growth in field-planted cuttings. Treatments included: soaking (1 vs. 3 days), rooting hormone (applied or not), season of collection (fall vs. spring), storage condition (pre-cut or uncut), location in the stool (from the base or top of stool), length (full-length whips vs. 30 cm cuttings), and material type (cuttings from a selected superior clone vs. from randomly selected trees). The greenhouse results showed that cuttings collected in the spring and from the superior clone had significantly better rooting success and early growth than cuttings collected in the fall and from randomly selected trees. Root mass was greatest with 1 day of soaking and rooting hormones had a negative effect on survival and no significant effect on growth. First year survival rates in the field were greater than 85%. The short cuttings grew on average 26 cm in height and 4.2 mm in basal diameter, while the long cuttings only grew 3 cm in height and 1.3 mm in basal diameter. The best pre-planting treatment was to soak the cuttings for 3 days in water without the use of rooting hormone. These results will be discussed.

RESPONSE OF ASPEN SEEDLINGS TO LIME, NITROGEN AND PHOSPHORUS APPLIED AT PLANTING OR ONE YEAR AFTER PLANTING

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The purpose of this work was to test likely aspen planting sites for limitation by inadequacies of four mineral nutrients. A factorial experiment was carried out with 3 levels of dolomitic limestone (Li) (supplying Ca and Mg), three levels of ammonium nitrate (supplying N), and two levels of triple superphosphate (supplying P). The experiment was conducted at Drayton Valley, Linaria, and Manning, Alberta. All trees of two seed lots were planted in year 1, but only half were fertilized at planting, and the remainder at the beginning of year 2.

After one year, the 12.5 g P (as 64 g triple superphosphate) per tree increased height growth 20 to 30% according to site and approximately doubled stem volume growth. Survival was increased 7% at Drayton Valley and Manning, but there was no effect at Linaria. After two years, trees at Drayton Valley receiving P fertilization at planting showed 128% greater stem volume growth than controls, but trees receiving P in year 2 showed only 12% greater volume growth. Corresponding values at Manning were 142% and 7%.

Dolomitic limestone had a small effect at Manning.

After two years a N x P x Li interaction showed that either N or Li increased growth in the absence of the other, and responses to P declined when both N and Li treatments were high. Nitrogen treatment increased leaf N concentrations in both years but effects on growth at Drayton Valley were small in year 1 and negative in year 2, particularly on survival, which decreased 33%. At Manning, N fertilization in year 1 increased growth and survival but second year N had no effect.

Differences in growth and survival between seed lots were large.

THE EFFECTS OF MECHANICAL SITE PREPARATION AND SUBSEQUENT WILDFIRE ON TREMBLING ASPEN (*Populus tremuloides* Michx.) REGENERATION IN CENTRAL ALBERTA, CANADA

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The objective of this study was to assess the regeneration response of trembling aspen (*Populus tremuloides* Michx.) to different mechanical site preparation (MSP) techniques (disc trenching, drag scarifying, and blading) commonly used in operational forestry and the specific microsites created by each treatment. This study was designed to measure regeneration after at least the first two growing seasons, however, a large wildfire burned 80% of the study sites at the beginning of the second growing season. Consequently, only limited second year data were available, but regeneration from the first growing season following the fire was also assessed. Results indicated that microsites where the forest floor was disturbed and the parent root system was only lightly injured were more conducive to suckering than undisturbed microsites or where the root system was severely injured. Also, the fire disturbance after the first growing season resulted in increased suckering relative to the untreated controls in the first year. These results suggest that aspen sites with thick organic layers or vigorous competition from other species can benefit from MSP when applied before the first growing season. In addition, if first year suckering is inadequate, subsequent disturbances such as prescribed fire have the potential to improve suckering provided the parent root system remains intact.

COMPETITION AND FACILITATION IN NEW ASPEN PLANTATIONS: INTERIM RESULTS

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Demand for *Populus* spp. is providing the impetus for the development of intensive plantations on agricultural land. Agroforestry, the concurrent production of trees with herbaceous crops and/or livestock, is one option for integrating tree production on agricultural land. Aspen seedlings must compete for light and soil resources with codominant vegetation and successful establishment of the plantation requires an understanding of vegetation interactions. Forages grown with aspen have the potential to facilitate tree growth by displacing more competitive species, adding nitrogen to the site, or protecting the seedlings from damage. Field studies are being conducted to isolate and quantify competitive and facilitative processes in mixtures of aspen seedlings, marsh reedgrass, and alfalfa and to isolate and compare the effects of root and shoot interactions (with the selective use of above and below-ground barriers) in these mixtures on the growth and survival of aspen seedlings.

Aspen survival after one year was 96% and was unaffected ($X^2 = 0.63$) by the presence of forage species. Aspen were subject to a number of damaging factors during the first year; aspen grown in monoculture had higher damage rates ($X^2 = 0.003$) than those grown in mixtures with forages. Aspen root-collar diameter growth declined ($p = 0.007$ to 0.06) when grown with alfalfa and marsh reedgrass, relative to its growth in monoculture. Aspen height growth ($p = 0.12$) and leaf number ($p = 0.64$) were unaffected by neighboring species. Aspen root-collar diameter growth improved ($p = 0.02$) when above-ground partitions were used to separate the foliage of forages from the aspen. Removal of above-ground interactions also decreased ($p = 0.03$) the number of aspen leaves. Root barriers separating aspen roots from those of the surrounding forage plants increased ($p < 0.0001$) the spring soil moisture available to the aspen seedlings, but did not result in improved aspen growth.

CELL SUSPENSION CULTURES, GENETIC TRANSFORMATION STUDIES AND PLANT REGENERATION FROM POPLAR SPECIES AND HYBRIDS

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The ability of plant cells and tissues to form various organs *de novo* has long been an object of interest and practical utility. Plant regeneration in tissue culture is a crucial aspect of plant biotechnology as it facilitates the production of genetically engineered plants, the release of disease-free plants from meristem cultures, and the rapid multiplication of difficult to propagate species.

Several cell suspension lines were established from friable callus cultures of *P. tremula* var. *erecta*, *P. tremuloides,* and the hybrid *P. nigra* X *P. maximowiczii*. Plants were regenerated from only one cell suspension line of *P. nigra* X *P. maximowiczii*, which maintained its morphogenic ability for more than 25 subcultures. Morphogenic, suspension derived cell aggregates were transformed with *Agrobacterium tumefaciens* carrying *lux* F and NPTII genes fused to CaMV 35S promoter and reintroduced to the liquid culture conditions. Resulting non-morphogenic cell suspension cultures were used to study the expression of CaMV 35S promoter during cell cycle stages.

Petiole explants of poplar hybrids *P. nigra* X *P. maximowiczii*, *P. deltoides* X *P. balsamifera*, *P. alba* X *P. tremula* var.*erecta*, and *P. deltoides* X *P. petrovskyana* were used to test plant regeneration ability in different culture conditions. The role of the plant hormones and especially the influence of giberellic acid on plant regeneration efficiency were discussed.

Highly efficient and reproducible *in vitro* technology for large-scale production of *P. tremula* var. *erecta* (120 000 plants produced since 1999) and *P. tremuloides* based on stabilized shoot culture methods were presented.

GENETIC DIVERSITY AND CLONAL STRUCTURE OF TREMBLING ASPEN (Populus tremuloides Michx.) IN THE CLAY BELT, QUÉBEC

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Trembling aspen is a pioneer species in the mixed boreal forest and appears abundantly after fire and full logging. In the absence of major disturbances, gaps enhance its recruitment but a gradual decrease in its density is observed until it's reduced to small patches in the oldest stands. In this study, we were interested to establish: 1) overall genetic variability along the clay belt of northwestern Québec and 2) potential relationship between clonal structure and natural disturbances along a temporal gradient. All samples were analysed at four microsatellite loci. Measures of genetic variation in four populations selected at the transition zone between mixed wood and conifer-dominated forests indicated that most of the variation occurred within rather than among the populations. R_{st} was 0.0409, slightly larger than that based on the infinite allele model (0.0323). Within each stand, five putative clones were sampled. DNA fingerprint identification allowed the differentiation of genetically distinct individuals within these putative clones and from 1.62 to 2.2 times more genetically distinct individuals were identified than by morphological identification. To examine further the potential clonal structuring, two stands that burned in 1823 and 1847 were selected in the Lake Duparquet Research and Teaching Forest (FERLD). The age of aspen trees present at each site was determined and three to four different cohorts were identified. In the first cohort recruited after fire as well as in the following cohorts regenerated in gaps we observed a high level of clonal diversity and a random spatial distribution of genotypes. No selection seems to be taking place between genets across cohorts Thus, after stand disturbance, suckers from different genotypes are likely to regenerate and to be closely mixed.

ADAPTIVE VARIATION IN COLD HARDINESS AMONG *Populus tremuloides* PROVENANCES FROM NORTHWESTERN ONTARIO

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Adaptive variation in cold hardiness was determined by electrical conductivity in the fall of 1999 for 20 aspen provenances from northwestern Ontario grown at three test locations. Significant variation was expressed among provenances that exceeded 70% for most date/site combinations. The first three principal components (PCs) summarized 68% of the total variance of 14 variables. PCs 1 and 2 represented different stages of development of cold hardiness; PC-1 mainly represented cold hardiness development after late September while PC-2 mainly explained cold hardiness development in early-mid September. Rankings of provenance cold hardiness were often inconsistent between the two developmental stages. A weak southwest to east cline was demonstrated for PC-1 while a clear east to west trend was found for PC-2. Multiple regression analysis of each PC against modeled climatic variables unique to each seed source indicated that growing season length and precipitation in August at the site of each seed origin were the best predictors of PC-1, or late-season cold hardiness. Conversely, temperature variables were always the best predictors of PC-2, representing early-season cold hardiness. The information revealed in this study will be helpful for guiding aspen seed transfer in northwestern Ontario.

EFFECTS OF CO_2 ENRICHMENT ON GAS EXCHANGE IN FOUR PROVENANCES OF TREMBLING ASPEN SEEDLINGS FROM NORTHWESTERN ONTARIO

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One-year-old trembling aspen (*Populus tremuloides* Michx.) seedlings from four northwestern Ontario provenances were exposed for 60 days to three CO_2 concentrations: 380 ppm (ambient), 540 ppm, and 700 ppm. Other environmental conditions were controlled at optimal for each treatment. Net CO_2 assimilation (NA) and water use efficiency (WUE) were significantly increased for all provenances at both elevated CO_2 levels, but intercellular CO_2 to leaf surface CO_2 ratio (Ci/Ca) was increased only at the 700 ppm concentration. Transpiration rate (E) and stomatal conductance (Gs) were significantly decreased at 540 ppm CO_2 but not at 700 ppm for the two southern provenances, while the two northern ones did not show this decrease. When measured at a common atmospheric CO_2 level of 360 ppm, a 10% down regulation of NA was observed for the 700 ppm treated seedlings, although no provenance differences were detected. We conclude that trembling aspen provenances from northwestern Ontario have the tendency to respond differently in their physiological acclimation to elevated atmospheric CO_2 while the different responses will most likely be expressed in plant-water relationships.

VOLUNTEER PAPER ABSTRACTS

"POPLAR TREE BREEDING"

THE POTENTIAL FOR HYBRIDIZATION BETWEEN NATIVE AND NON-NATIVE POPLARS IN CENTRAL ALBERTA

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In central and northern Alberta there are two native *Populus* tree species, *P. balsamifera* and *P. tremuloides*, and no naturally occurring hybrids. However, approximately 21 different varieties of hybrid poplars are currently being used on private land in both shelterbelts and poplar plantations. It is well documented some hybrid poplars can exhibit rapid growth rates and resistance to fungal pathogens and insect pests. Therefore, the interest in using hybrid poplar material by the forest, oil, and gas industries is rising. However, the deployment of hybrid poplar material is restricted to private land due to provincial Government regulations (currently under revision) which were put in place to avoid potential ecological risks. This research project was initiated in response to the increasing interest in using hybrid or exotic material and to aid Government discussions regarding the deployment of non-native poplars by understanding the causal factors responsible for hybridization. Hybridization may lead to a process called introgression where genes are exchanged between two sympatric species (native or introduced) which may potentially compromise the gene pool of native populations through time. In this research project three questions were explored which looked at the causal factors responsible for hybridization between native and non-native poplars in both the Fort Saskatchewan and Athabasca region: 1) what are the flowering patterns of both native and non-native poplars and to what extent do the overlapping flowering patterns contribute to the potential for hybridization, 2) are native and non-native poplars genetically compatible under greenhouse conditions, and 3) is natural hybridization occurring by assessing the leaf morphology of open pollinated seedlings? This presentation focused on the first research question.

HYBRID ASPEN, A MIRACLE OR THREAT?

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Since the mid 1990's, commercial planting of hybrid aspen (*P. tremula* L. X *P. tremuloides* Michx.) is of increasing interest for Finnish forest owners. However, in the view of forest certification programs, environmental groups in Finland, as well as in Estonia, are concerned about the effects of using hybrid aspen at a large scale because half of its genome originates from the exotic North American aspen. They are afraid that progenies of hybrid aspen will spread rapidly outside the plantations and that pure native aspen may be suppressed in the future. The discussion if hybrid aspen will be allowed for reforestation or for afforestation of agricultural fields in Finland is still on-going. In the mean while the Finnish Forest Research Institute Metla has started a research project in order to study the risks for spreading *P. tremuloides* genes into the Finnish landscape. The project focuses on the ability of hybrid aspen to sexually propagate under Finnish conditions.

EARLY RESULTS FROM AN ASPEN PROVENANCE TRIAL IN WESTERN CANADA

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A trial to investigate provenance differences in aspen (*Populus tremuloides* Michx.) was established on five sites in Western Canada in 1998 by members of the Western Boreal Aspen Cooperative (WBAC). The trials were established by Alpac, DMI, and Weyerhaeuser Drayton Valley in Alberta, by Slocan in northeastern British Columbia (BC) and by Weyerhaeuser Prince Albert in Saskatchewan. The objective was to evaluate differences in survival and growth for a number of seed sources planted in common environments on five contrasting sites.

Seedling stock from 43 seed sources was established in five-tree row plots with six replications per site. Thirty-seven of the seed lots originated from within the three WBAC breeding regions, one seed lot came from Fort Nelson in BC and five seed lots originated in Northern Minnesota. The trials were measured after one growing season for total height and root collar diameter.

After one year, the mean heights were approximately 100 cm (range 50 to 150 cm) and the mean root collar diameter was about 15 mm (range 10 to 25 mm). Analysis of variance revealed significant provenance differences for both traits. The five Minnesota seed lots were consistently among the top ranked on all sites for height and diameter. The single Northern BC seed lot was consistently among the bottom ranked on all sites. Local seed lots deployed within their provenance were usually middle ranked.

While early performance may ultimately prove to be an unreliable predictor of adaptation and growth potential at a more advanced age, the large and significant provenance differences suggest that these trials should be followed for several more years. Further provenance research in aspen is clearly warranted.

VOLUNTEER PAPER ABSTRACTS

"CONIFER MOLECULAR GENETICS"

RECENT ADVANCES IN THE WHITE SPRUCE BREEDING PROGRAM IN QUÉBEC

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White spruce breeding activities started in Québec in the late 1970s with the establishment of first generation seed orchards and the selection of superior genotypes for setting up the breeding populations. Trees were selected in provenance and family tests established two decades earlier. A two-step breeding strategy was retained. First, general combining ability of selected trees was estimated using progenies produced via polycrosses. Second, each selected tree was crossed with two others to produce full-sib families with the best pair matings being selected for the next breeding generation. Controlled crosses were carried out in the early 1990s and progeny tests were set up using control seed lots as well.

While waiting for the newly established progeny tests to be old enough to provide good estimates of general combining ability of the selected trees, data were collected in another series of eight open-pollinated tests established during the 1970s and 1980s. Breeding values were estimated at about 15 years of age using Best Linear Projection. Two, 1.5 generation breeding orchards were set up. Both seed orchards are composed of the 25 best families of the balsam fir-white birch and the maple-white birch ecological domains. Expected genetic gains are 15% and 19%, respectively. Production of seed is expected by 2010.

In the past few years, data were collected in recently established progeny tests and preliminary recommendations were made. Hence, it was recommended that crosses for the best 30 full-sib families be repeated and that they be bulked up using rooted cuttings. These 30 full-sib families showed a 25% superiority in height to control seed lots, 5 years after planting. All means are being taken to benefit as much and as quickly as possible from investments in the white spruce breeding program.

GROWTH AND ADAPTATION OF *Larix gmelinii* AND *L. sibirica* IN NORTHERN ONTARIO 20 YEARS AFTER PLANTING

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Survival and growth of 18 open-pollinated families of *Larix gmelinii* and 4 seed lots of *L. sibirica* were assessed across 6 sites in Ontario, 20 years after test establishment. Results indicated that vegetation competition in the first 4 years after planting contributed significantly to the high mortality of young planted larch trees. If they survived the first 4 years, both *L. gmelinii* and *L. sibirica* trees adapted and grew well in northern Ontario, attaining an average height of nearly 11.0 m and diameter of 13.0 cm by age 20. Substantially more wood was produced by the exotic larches when compared with other native species under similar growing conditions. Based on the frost damage observed in the first 4 years, future introduction of *L. gmelinii* should focus on more continental provenances to enhance cold hardiness. No significant differences in growth and adaptation were detected among the open-pollinated families or seed lots within the 2 species.

CAN CLONAL REPLICATION OF GENETIC TESTS FOR ADVANCE-GENERATION SELECTION ELIMINATE THE NEED FOR POLYCROSS ASSESSMENT OF BREEDING VALUE?

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Selection of breeding parents in many tree improvement programs is based on a combined index of family and individual performance. While family performance is estimated from many observations, individual performance is assessed by a single observation from each candidate phenotype. A progeny test using a pollen mix (“polycross”) is commonly performed to obtain a good estimate of breeding value of candidate selections, normally before any decisions are made regarding which should be used for seed production or advance-generation breeding. One way to increase the precision of within-family selection is to establish clonally replicated tests, where one can make several observations of performance for an individual genotype. Eliminating the need for a separate polycross test would save time and resources. On the other hand, establishing clonally replicated tests would require an extra propagation step, adding time, complexity and cost, and fewer genotypes could be evaluated.

To study these tradeoffs, we simulated full-sib crosses and within-family selection in a simple breeding population, using a parameter-based computer model. We used two approaches to testing: 1) a seedling test, followed by polycross assessment of breeding value and 2) a clonally replicated test, performing within-family selection on clone means. The best trees in each cycle, selected on the basis of the polycross test or clone means, respectively, were used as seed-orchard parents and orchard gains estimated. Scenarios were compared at fixed levels of resources and, in the case of clonal replication, optimum numbers of ramets per genotype.

For all scenarios evaluated, clonally replicated tests were superior to polycross testing, even when the cost of propagation increased as much as five times, reducing the number of test plants that could be established under fixed resource levels. The simulations support the utility of clonal propagation as a tool in genetic testing, even when normal plantation deployment is with seedling stock.

INTENSIVE TREE BREEDING: EXPLORATION OF NON-ADDITIVE GENETIC VARIANCE

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Worldwide, almost all conifer tree breeding programs adopted population improvement approaches and used additive genetic variance only. This is because: 1) most conifer open-pollinated progeny trials have shown plenty of additive genetic variance and 2) the majority of control-pollinated progeny trials have shown little or diminishing non-additive genetic variance. Despite all inbred experiments in conifers so far demonstrating a great deal of non-additive genetic variance in growth and fecundity traits, selfing as a breeding tool to purge deleterious alleles was not encouraged and adopted in conifer breeding programs. Sib- or random-mating was recommended as a better option in the early generations of conifer domestication. In contrast, major out-crossed crops such as maize, sorghum, and sunflower explored non-additive genetic variance extremely successfully in their inbreeding-hybrid breeding programs. Recent results from two long-term experiments in Australian radiata pine (*Pinus radiata* D. Don) have shown large quantities of non-additive genetic variance in growth traits. The significance of these non-additive genetic variances in radiata pine was studied and various methods to explore their utilization in tree breeding and deployment programs was discussed. An experimental inbred population for radiata pine including selfing to three generations and crosses among selected progenies from two generations of selfing was established to explore the use of non-additive genetic variances in a radiata pine breeding program.

VOLUNTEER PAPER ABSTRACTS

"CONIFER MOLECULAR GENETICS"

IMPROVING ESTP DISCOVERY BY COMBINED MOLECULAR APPROACHES

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The use of codominant and informative markers such as microsatellites or ESTPs (expressed-sequence-tag-polymorphisms) is necessary to estimate consensus genetic maps within and among taxa. Our goal is to develop anchor markers for spruces in order to evaluate map syntheny. In this study, EST primer pairs developed from black spruce (*Picea mariana* [Mill.] BSP), Norway spruce (*P. abies* [L.] Karst.) and loblolly pine (*Pinus taeda* L.) were screened for polymorphism on panels of pedigree parents for each of white spruce (*P. glauca* [Moench] Voss) and black spruce. Out of 172 primer pairs, 122 (71%) resulted in positive amplifications without multi-banding. So far, the occurrence of polymorphism has been tested with 70 of these suitable primer pairs for black spruce and with 61 primer pairs for white spruce. Respectively, 50 (71%) and 46 (75%) of these showed polymorphism either by agarose gel electrophoresis or by Denaturating Gradient Gel Electrophoresis (DGGE). Out of these, 27 (56%) were common to both species. When no polymorphisms were observed, we sequenced PCR fragments in search of single nucleotide polymorphisms (SNPs). Because the more affordable DGGE is used for genotyping SNPs in mapping populations, sequencing allows to quickly identify additional SNP-bearing markers for which DGGE conditions could be optimized. To increase the speed and reduce the cost of SNP discovery by sequencing, DNA pooling strategies were tested. Well characterized DNA samples were pooled in different ratio mixtures before and after PCR amplification in order to determine their minimum relative abundance for SNP detection by sequencing. SNPs with a pool frequency higher than 10% could be detected. Pooling DNA samples before or after PCR amplification had no effect on the detection of SNPs by sequencing.

CROSS-SPECIES AMPLIFICATION OF MITOCHONDRIAL DNA REGIONS IN CONIFERS: DETECTION OF POLYMORPHISM AND VARIATION WITHIN AND AMONG SPRUCE SPECIES

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Universal primers currently used to amplify specific non-coding regions of the angiosperm mitochondrial genome and newly developed primers for additional non-coding mtDNA regions were tested for their ability to direct DNA amplification in 12 conifer taxa and to detect polymorphism within and among eight *Picea* species. PCR amplification was successful with 10 of the 12 primer pairs tested in most of the taxa. In conifers, indels and substitutions were observed at several loci. These polymorphisms made it possible to distinguish among families, genera, and in some cases, between species within genera. In spruce species, interspecific polymorphisms were detected at four loci and suitable intraspecific variation was observed in three of these four mtDNA regions. One of these polymorphisms (in the *SSU rRNA* gene) involved an insertion-deletion and was directly detectable on polyacrylamide gels. The polymorphisms at the two other loci (in the genes *nad1* and *nad5*) were revealed after digesting the PCR products with restriction enzymes. The remaining marker (the *nad4L-orf25* intergenic region) exhibited a multibanding pattern in most of the spruce species. Maternal inheritance, expected for mtDNA in conifers, was observed for all polymorphic markers except the *nad4L-orf25* intergenic region, suggesting its possible duplication and transfer to the nucleus. Pooling of the variation observed with the remaining three valid markers resulted in two to six different mtDNA haplotypes within the eight spruce species surveyed. These mitotypes are likely to be more informative than single-locus haplotypes due to evidence of intra-genomic recombination observed in some spruce taxa. They shall be particularly useful in studies concerning phylogeography and the dynamics of hybrid zones.

MICROSATELLITE LOCI REVEAL A NORTHERN GLACIAL REFUGIUM AND A ZONE OF SECONDARY CONTACT IN WESTERN RED CEDAR (*Thuja plicata*)

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Western red cedar (*Thuja plicata* Donn) occupies an extensive range along the west coast of North America extending from northern California to southern Alaska and in the interior from east-central British Columbia to northern Idaho. We used 8 microsatellite loci to analyze patterns of genetic diversity and structure in 23 populations covering the range of western redcedar. A dendrogram revealed two distinct groups: a north-western clade made up of northern coast and northern Vancouver Island populations and a south-eastern clade made up of southern coast and interior populations. This north/south split along the west coast of North America has also been observed in other plant species and suggests the presence of two separate refugia during the last glacial period. Steep clines in allele frequencies point to Vancouver Island as a zone of secondary contact between the two groups. Overall differentiation between populations was low and genetic distances increased linearly with geographical distance indicating high levels of contemporary gene flow. Northern populations also showed reduced genetic diversity as measured by the number of alleles per locus and expected heterozygosity.

VOLUNTEER PAPER ABSTRACTS

“ECOLOGICAL GENETICS”

CATALOGUING *in situ* PROTECTION OF GENETIC RESOURCES FOR FOREST TREES IN BRITISH COLUMBIA

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Loss of genetic diversity can have a variety of causes and might take place unnoticed even in species that seem to be in no danger. Establishing *in situ* reserves can be a very efficient method to protect genetic diversity in tree species if they have the right size and spatial distribution. The idea behind this “coarse filter” approach to gene conservation is that by providing spatial coverage for landscape level units we will automatically cover genetic variation as well. A common approach to assess the level of protection needed is to utilize census information on the population size and distribution for tree species of concern. Based on existing botanical records from the Provincial Ecology Program we modeled and mapped distribution patterns of 48 tree species in British Columbia (BC). Then, we used geographic information systems for analysis of spatial threats (such as habitat destruction) and gap analysis (such as lack of protection in a particular region). Some tree species in BC are very common and virtually ineradicable while others have been reduced to a few small populations. In this first assessment, we determined where species fall along this risk continuum. This will help to allocate resources for subsequent analytical work efficiently and to assess the need for genetic data on different species.

GENETIC VARIATION IN VULNERABILITY TO XYLEM CAVITATION OF DOUGLAS-FIR FROM THE SUB-MARITIME SEED ZONE IN BRITISH COLUMBIA

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Under severe water stress, xylem cavitation occurs in plants. Cavitated xylem may permanently lose the capacity of transporting water from roots to leaves and can lead to tree death, if a high proportion of xylem cavitates. Thus, vulnerability to xylem cavitation is critically related to drought tolerance of the tree. Vulnerability to cavitation can be measured on seedlings under laboratory conditions. Genetic variation in vulnerability to xylem cavitation of three-year-old seedlings was examined among 12 populations (locations) from the Sub-Maritime seed zone in British Columbia, a transitional area from maritime to continental climates with steep environmental gradients for precipitation and temperature. Significant variation was found among populations in vulnerability to cavitation and this variation was correlated with some geographic and climatic variables of population origins. Vulnerability to xylem cavitation was negatively correlated with the distance to the coast and with elevation, and positively correlated with mean annual temperature, mean coldest month temperature, and annual frost-free period. Therefore, this trait may be important in refining seed transfer guidelines for this region.

AN AREA-BASED CLUSTER APPROACH TO DELINEATING BREEDING ZONES

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A breeding zone delineation scheme is developed based on the idea that the maladaptation in each breeding zone is proportional to its genetic variation and size. Maladaptation on a regional scale is minimized using disjoint cluster analysis to assign each predicted adaptive value (cell) of a region to one of a pre-determined number of clusters (breeding zones), such that the sum of the squared distances between each value and its cluster mean is minimized, thereby minimizing average transfer distance and maladaptation.

The procedure is illustrated using adaptive values of 69 Interior spruce open-pollinated families from southeast British Columbia as dependent values and predicted climatic values of the seed sources as independent values in multiple regression to develop a genecology model (R^2 = 0.64). Adaptive values of each 1.5 x 1.5 km cell in the 80 000 km^2 region were predicted using the model and the values subjected to disjoint cluster analysis to identify optimum breeding zone boundaries that are mapped using a geographic information system.

A maladaptation index is developed and applied to three delineation schemes and breeding zone arrangements involving 1, 2, 3, and 4 breeding zones. The regional maladaptation index declined with increasing number of breeding zones and was consistently smaller using area-based cluster analysis rather than when zones were devised having equal elevational or adaptive band widths.

The procedure should assist in devising breeding zones which result in minimum maladaptation on a regional scale and in quantifying the relationship between maladaptation and number of breeding zones.

TREE SEED WORKING GROUP

WORKSHOP ABSTRACTS

Workshop Theme

“Genetic and Physiological Control of Seed Dormancy and Germination”

ADAPTIVE VARIATION IN DORMANCY AND TIMING OF GERMINATION OF SEEDS OF NORTH TEMPERATE CONIFERS

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"Seed dormancy and germination are complex adaptive traits of higher plants that are influenced by a large number of genes and environmental factors" (Koornneef *et al*. 2002. Current Opinion in Plant Biology 5(1): 37-42).

Seed dormancy is defined as the failure of an intact viable seed to complete germination under favorable conditions (i.e., a threshold trait). However, adaptive variation in dormancy is usually reported in time to (or rate of) germination or emergence. Times or rates are dependent on degrees of dormancy and, as continuous variables, are amenable to standard statistical analyses.

Degree of dormancy is determined by "innate" controls within the seed and by interactions between these controls and external environmental factors. Innate controls may be genetic and reside in the embryo (segregation within and among families) or in covering structures (segregation among families) or they may be non-genetic and influenced by maternal environment or by cone and seed handling treatments. Innate controls interact with a number of external environmental factors to regulate expression of dormancy. The two external factors most frequently reported as being associated with adaptive variation are duration of moist chilling during winter and incubation temperature in the spring.

The germinating seed has maximum vulnerability to the physical environment. Therefore, time of germination should be adapted to local conditions, late enough to avoid frost, but early enough for the germinant seedling to harden off before moisture stress or frost again become critical. Because dates of frost and time of moisture stress vary greatly across North Temperate habitats, it is expected that there will be much variation in dormancy across the landscape. For the most part, this has been observed, but with some complications.

The following observations were drawn from personal work and from a survey of the literature. The observations are mostly general; if reported only for a single species, that species is named.

1) Most tests have been conducted in the laboratory or with artificially stratified and spring-sown seed. In other words, seeds were moist chilled at a temperature low enough to limit embryo development then incubated at a temperature warm enough promote growth of the embryo. Chilling and embryo development were separated in time. In a test of autumn-sown Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seed, germination itself occurred in early spring in a temperature range (5–8°C) at which effective moist chilling also should be occurring. That embryo development and chilling occur contemporaneously provides a further level of complexity in the adaptive expression of dormancy.

2) There is very large local variation in dormancy or germination timing, both among families and among seeds within families. This variation is important because of local microsite and temporal (year to year) climatic variability.

3) Nevertheless, variation among locations often is significantly larger, sometimes much larger, than variation within locations.

4) Physiographic distribution of locations often is inconsistently related to presumed adaptive variation (for

example, dormancy has been reported to decrease, increase, and not to be related to both latitude and elevation).

5) Test condition (year-of-sowing effect with autumn-sown Douglas-fir) influenced the pattern of variance across the landscape. There was interaction between test condition and adaptive "pattern".

6) One consistent report was that seed from moist or maritime locations had deeper dormancy than seed from dry or continental locations.

Several reasons were suggested for the inconsistencies in adaptive patterns (number 4 above).

1) Maternal environmental and cone and seed handling effects were confounded with location effects.

2) Seed dormancy is adapted to climatic variation, but patterns of adaptive variation are usually reported in physiographic terms (latitude, elevation, etc.). The relation between climatic and physiographic variables can differ greatly from place to place in the North Temperate Zone (examples were given).

3) The test regime affects the expression of adaptive pattern. Many different combinations of chilling and incubation were used in the tests that were surveyed.

4) Different species may have adapted in different ways with the consequence that some of the differences in patterns may be due to interspecific variation.

To return to the initial quote, seed dormancy and germination are indeed complex traits, sufficiently complex that at the level of current understanding it is difficult to give many generalizations.

THE BREAKDOWN AND USE OF SEED RESERVES IN NORTH TEMPERATE CONIFERS AND ANGIOSPERMS

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Proteins, triacylglycerols (TAGs), and carbohydrates are the major reserves of conifer and angiosperm seeds. They are located in organelles found within the storage parenchyma of the megagametophyte and embryo. Amino acids and soluble carbohydrates, generated from reserve breakdown, are exported to the developing seedling where they are used to support seedling growth and development until full autotrophy is attained. In mature seeds, more than 70% of these reserves are located within the conifer megagametophyte and the angiosperm cotyledons. Consequently, developing tree seedlings are dependent upon these storage tissues for much of their nutrition until photoautrophic independence is attained. Rapid breakdown of megagametophyte and cotyledon reserves occurs following germination. Work with loblolly pine (*Pinus taeda* L.) has shown that the seedling is required to maintain rapid reserve breakdown in the megagametophyte. In relation to this, the seedling influences the level of activity of several key enzymes of megagametophyte TAG breakdown. The reverse is also true. The megagametophyte not only provides nutrition for the seedling during its early development, it also exerts control over the utilization of megagametophyte-derived nutrients by the seedling; it does this through the induction and maintenance of seedling enzymes involved in nutrient assimilation. Clearly, in loblolly pine, germination and early seedling growth involves a complex set of interactions between the megagametophyte and seedling that are bi-directional.

WOOD QUALITY WORKING GROUP

WORKSHOP ABSTRACTS

Workshop Themes:

"Variation in Wood Quality"
"Effects of Intensive Silviculture on Wood Quality and End Uses"
"Wood Technology"
"Incorporating Wood Quality and End Uses Into Tree Breeding Programs"

SITE INDEX VARIATION IN WOOD DENSITY OF DOUGLAS-FIR: LOOKING FOR TRENDS

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Due to the negative correlation between wood density and height growth, many of the fastest growing trees were not selected for second generation orchards in the Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) program in British Columbia. However, if sites or regions could be identified that affect wood density in a positive way, then these fast growing families could be deployed there. To explore this strategy a pilot study was initiated. Three sets of 10 full-sib families were evaluated on six sites each on Vancouver Island (for a total of 18 sites). Wood density was determined on 12 progeny per family per site using increment cores and the maximum moisture method. Wood density averages ranged from 0.378 g/cm^3 to 0.445 g/cm^3 without any geographical patterns detectable. However, when site averages were adjusted by removing family means, a strong south-north pattern was evident. Adjusted wood density values were generally higher on the Mid-Island sites and on Northern Vancouver Island. The correlation between site quality (as expressed as site mean height at age 12) and adjusted wood density values was low (R^2=.22), indicating that high wood density wood can be grown even on productive sites on Mid- to North Vancouver Island. Therefore, by selecting specific sites or regions, it is possible to deploy the fastest-growing families without sacrificing wood quality. However, more sites must be sampled to produce a denser map of site index for wood density.

WOOD AND FIBRE QUALITY OPPORTUNITIES FOR SELECTION OF SUPERIOR CLONAL MATERIAL

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Wood quality is defined by the intrinsic morphological and chemical components of wood and, as such, plays a critical role in determining the overall economic value of a stem. In addition to growth rate, the rapid and routine measurement of properties such as wood density, fibre length, fibre coarseness, fibril angle, and chemistry can be used to select superior clonal material. Such tools are used to predict end-product quality throughout the forest products value chain and, as such, represent a critical component in modern plantation development. In this study, we present a comprehensive assessment of aspen clones from throughout British Columbia which clearly indicates that the potential for selecting superior clonal material exists. Quantifiable differences which can significantly increase the economic value of the end-product through enhanced processing efficiency and differentiated products, specific to the pulp and paper industry, were observed. Multiple clonal families were examined. Differences in site quality factors and site index were shown to be negligible. Significant growth rate differences were observed. Wood characteristics which affect mill operations such as wood density, varied from ~300 – 430 kg/m^3, and mature wood fibre properties which influence paper strength performance, such as fibre length, varied from 0.85 – 1.1 mm.Variations in pulp yield and H-factor, required to achieve target residual lignin content prior to bleaching, were also significantly different among the clones, confirming that significant chemical and morphological differences exist. From this study, it is evident that within the clonal material selected for plantation establishment based on growth, yield, and disease resistance, there exist subsets of clones which exhibit superior wood quality traits that can significantly influence end-product quality and further improve plantation economics.

EFFECT OF STAND DISTURBANCE ON EXTRACTIVE CONTENT OF DOUGLAS-FIR HEARTWOOD

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Extractives can have a major impact on the properties of heartwood. However, our understanding of the process of heartwood formation and extractives production is limited. For example, there are few data on how silvicultural practices in managed forests or environmental disturbance might affect heartwood extractive content. This study assessed the effect of thinning and insect defoliation on the annual growth increment and the extractive content of heartwood of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) trees. Annual growth increment increased after thinning and this increase was associated with an increase in the extractive content of the heartwood estimated to have been formed after the thinning. Annual growth increment decreased after insect defoliation and this decrease was associated with a decrease in the extractive content of the heartwood estimated to have been formed after defoliation. These results suggest that silvicultural treatments and disturbances that affect growth rate may have associated effects on wood durability.

EFFECTS OF PRE-COMMERCIAL THINNING ON THE PHYSICAL AND MECHANICAL PROPERTIES OF CLEAR WOOD IN BALSAM FIR (*Abies balsamea* [L.] Mill.)

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The effects of pre-commercial thinning on physico-mechanical properties of clear wood in balsam fir (*Abies balsamea* (L.) Mill.) were evaluated on small (10mm x 10mm x 150 mm) clear wood specimens. The chosen methodology allowed for an examination of different wood quality characteristics from pith to bark at 3 different heights along the stems. Wood density, longitudinal (Lg) shrinkage, modulus of elasticity (MOE), and modulus of rupture (MOR) were measured on a total of 466 specimens. Surprisingly, for all data, wood density was positively correlated to Lg shrinkage and negatively correlated to MOE ($p < 0.0001$). For the specimens of wood produced after the pre-commercial thinning treatment, wood density was positively correlated to both MOE and MOR ($p < 0.0001$). Unusual correlations were attributed to the presence of compression wood near the pith of the trees. The effect of the treatment was evaluated through the relationship between cambial age and the four wood quality characteristics measured. For MOE and MOR, there is a linear relationship until the thinning treatment is applied. Polynomial models seem better suited for wood density and Lg shrinkage. Overall, the results suggest that the thinning treatment had a negative impact on all wood characteristics studied. A refined multivariate regression model is being developed to further quantify this impact.

COMPETITIVE INTERACTIONS IN DOUGLAS-FIR/RED ALDER MIXTURES: IMPLICATIONS FOR WOOD QUALITY

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Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and red alder (*Alnus rubra* Bong.) commonly regenerate and occupy the same sites in the Pacific Northwest. Interactions between these species can be competitive, facilitative, or a combination of both over time. A number of factors have recently led to increased interest in managing these two species in mixture for commercial production and on-going investigations are yielding important information about how interactions between the two species affect stand structure and productivity.

Many wood quality attributes are ultimately controlled by physiological processes, which in turn are affected by competition within a forest stand. This research addresses how stand structure in young, mixed Douglas-fir/red alder plantations is associated with variations in stem form, knot size and distribution, and the phenology of wood formation. With better information about such implications for wood quality, forest managers will be able to make more informed choices about management of Douglas-fir and red alder mixtures.

EFFECTS OF PRE-COMMERCIAL THINNING ON GROWTH INCREMENT AND WOOD DENSITY IN JACK PINE (*Pinus banksiana* Lamb.)

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Precommercial thinning (PCT) is practiced to accelerate the diameter growth of individual trees and thus to reduce the rotation age of the stand. This study examined the effects of PCT on growth increment and wood density in jack pine (*Pinus banksiana* Lamb.). One hundred fourteen sample trees were collected from the control and three thinned stands (4 x 4, 5 x 5, and 7 x 7 feet). Ring width and wood density of individual rings were measured by X-ray densitometry. Response to the thinning treatment was evaluated at 8 foot intervals for each sample tree. Only trees from the 7 x 7 feet treatment showed a significant response in annual volume increment. Results suggest that a heavy thinning intensity is needed to achieve a significant increase in annual volume increment. No significant differences in average wood density were found between the thinned stands and the control at every height. However, PCT had some effect on earlywood density at 8 and 32 foot heights.

IMPACT OF STAND DENSITY MANAGEMENT ON PRODUCT QUALITY AND FINANCIAL RETURNS IN THE S-P-F SPECIES

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The potential shortage of large-size sawlogs is emerging as a constraint to the growth and prosperity of the forest industry in eastern Canada. To sustain the sawlog supply, the forest industry in eastern Canada is embracing stand density regulation regimes (e.g., precommercial thinning and commercial thinning) to accelerate the diameter growth of individual trees and to shorten the rotation age for sawlog production. While several studies have shown that stand density regulation is generally effective in accelerating the diameter growth, no studies have quantified the effects of stand density regulation on end-product quality in eastern species. Moreover, the economics of these silvicultural regimes has not been evaluated. In recent years, a series of research projects has been initiated by Forintek to evaluate the impact of stand density regulation regimes on product quality and financial returns in the S-P-F species, the three most important lumber species in eastern Canada. This paper reports on initial spacing (IS) in black spruce, precommercial thinning (PCT) in balsam fir, and commercial thinning (CT) in jack pine.

The three studies show that stand density regulation at any stage (IS, PCT, and CT) is effective in accelerating the diameter growth of individual trees in the three species although maximum fibre volume production may not be achieved. With increasing spacing, stem taper, crown size, and branch diameter tend to increase and, consequently, lumber quality is negatively affected. The magnitude of the negative effect, however, depends on the thinning intensity and species. It appears that lumber quality does not decrease significantly as long as stand density stays over 2 000 trees/ha. Economic analysis indicates that both PCT and CT are economically viable silvicultural regimes for the lumber industry but a moderate to heavy thinning intensity is needed to achieve a significant increase in average diameter growth to justify the treatment costs. A significant increase in average tree diameter in the thinned stands will lead to a significantly higher lumber value recovery per m^3 of wood. In addition, a larger average tree diameter reduces the logging and lumber manufacturing costs. The initial spacing study showed that a wider initial spacing than traditional 2 x 2 m for black spruce yields higher economic returns if the stands are managed for sawlog production. An initial spacing of 2.7 x 2.7 m may lead to a significant decrease in lumber quality despite its highest benefit/cost ratio.

WOOD BIOTECHNOLOGY AND ITS APPLICATION IN WOOD PRODUCTION

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Wood is a renewable resource and plays an important role in the world economy. The application of biotechnology to forestry and wood products has been explored to a limited extent worldwide. A literature search of the recent development of wood products biotechnology and biotechnology used for wood protection was conducted. This paper reviews previously published research on the use of biotechnology in wood protection. It discusses the potential benefits and constraints to the applications of biotechnology in this area. It covers the needs and opportunities for linking biotechnology and pest control. The use of modern biotechnology for the development of new biocontrol agents, the linkages between biotechnology and tree breeding in relation to pest and disease resistance, some alternative strategies as to how transgenes may be best deployed in relation to pest resistance, and the development of new diagnostic systems are summarized. The future trends on the development and the applications of this technology in wood protection are discussed. The key challenge faced by the wood industry in the development and the use of biotechnology-derived products or processes for wood protection lies in the bio-product registration. Public attitudes against the environmental release of genetically engineered organisms may also have a strong effect on the development of these types of bio-products. Future efforts in the application of biotechnology in wood protection are recommended as providing the knowledge base and the technology to enhance tree breeding processes for wood pest resistance, developing safe and effective deployment strategies for sapstain and decay control biotechnology derived products, contributing to the availability of energy efficient and environmentally friendly wood protection processes, and fostering the uptake of forest sector biotechnology by the wood products manufacturing industry.

COMPRESSIBILITY OF EARLY- AND LATEWOOD AND ITS INFLUENCE ON MECHANICAL PULPING

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Mechanical pulping, such as TMP, is known to be energy intensive particularly during the fiber development stage where the separated fibers are flexibilized and fibrillated with repeated compressive-shear treatment. This mechanical conditioning is important to make the fibers usable for papermaking. However, such mechanical treatment is inevitably inefficient in energy use because of the mobility (vs. wood grinding) of the chips in the refiner which operates with a fixed gap. It is, therefore, important to mechanically condition the chips before refining them. Recent studies at our laboratory had shown that conditioning of wood chips by static compression prior to refining helped to reduce energy consumption while improving pulp quality. In chip refining it is desirable that the compression precedes the shear to establish favourable conditions for the benefit of the latter. To advance the understanding of the effects of compression on the structural failures of early- and latewood, compression tests with large deformation were conducted and the modes of breakdown of the two types of fibers in atmospheric refining were also examined.

Compression tests on hybrid larch specimens were conducted, at room temperature, using an Instron machine. Water-saturated specimens were loaded in radial, tangential, and longitudinal directions. Stress-strain curves were generated and physical failures of the early- and latewood were examined microscopically. Atmospheric refining characteristics of unpressed chips were also examined microscopically. The results showed that in radial compression the earlywood fibers were responsible for the majority of the overall deformation and that the latewood fibers tended to separate from each other rather than collapse as opposed to those in earlywood. Radial compression induced delamination of the cell wall which was particularly substantial in earlywood fibers. In longitudinal and tangential compressions, the initial failures of specimens occurred in the area bordering the early- and latewood. In atmospheric refining, the earlywood broke down into chunky particles of varying sizes and forms while the latewood disintegrated into slender bundles and well separated fibers.

SUITABILITY OF SHORT ROTATION HYBRID POPLAR FOR LVL/PLYWOOD PRODUCTS

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As increasing volumes of short-rotation hybrid poplar reach maturity, veneer manufacturers were particularly curious of the suitability of these hybrids for the manufacture of laminated veneer lumber (LVL) and plywood. This study aimed to characterize this species for LVL/plywood products. Twenty-one-year-old hybrid poplar logs from plantations growing in Québec were peeled and dried at Forintek's pilot plant. Veneer sheets were sampled and their properties measured. The poplar was found to peel well and produce a smooth veneer surface. In a commercial dryer, the test veneer handled easily and dried satisfactorily, producing flat sheets. It was noted, however, that due to high initial moisture contents, drying times tended to be longer than with aspen or common softwoods. Densities for the two clones under test were not statistically different, but veneer stress grading revealed that one clone offered a significantly higher modulus of elasticity (MOE) than the other. With an average MOE of 1.24 million psi, the poplar veneer rated lower than Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (1.80 million psi), aspen (*Populus* spp.) (1.74 million psi), and white spruce (*Picea glauca* [Moench] Voss) (1.51 million psi). Meanwhile, veneer stress grading identified 30% of the hybrid poplar population that could be extracted to make LVL at the 1.5 million psi stiffness level. Further pilot plant tests established that higher LVL stiffness levels could be obtained through selective placement of stress graded veneers and combinations with other species. In plywood applications, hybrid poplar appeared interchangeable with aspen for most situations. For applications where higher strength and stiffness are required, stress grading and combinations with stiffer species also provided a wide range of solutions. Hybrid poplar logs of the size and quality evaluated in this study will produce a high yield of face grade veneer for appearance applications.

3D VISUALIZATION OF WETWOOD WITHIN SUBALPINE FIR STEMS

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Software was developed by which virtual 3D subalpine fir (*Abies lasiocarpa* [Hook] Nutt) logs can be re-constructed and theoretically sawn an infinite number of times to obtain data for evaluating sawing methods and distribution of wet-wood and knots.

Logs from 16 sublpine fir trees were sawn into 25 mm thick flitches and each flitch surface was digitally photographed. Data regarding flitch shape, wet-wood, and knot patterns were obtained from the digital images by using image processing software. The 3D re-construction of virtual logs was based on the measurements obtained from these digital images. The software creates 3D-logs with clearwood, knots, and wetwood patterns. The software also makes it possible to compare different ways of sawing the virtual logs by placing vertical and horizontal cuts through the log. Finally, the software enables quantitative measurements of volume and location of wet-wood and knots.

As a result, interesting trends point the way to a better understanding of wet-wood and knot variations as influenced by the sawing methods. The developed log data re-construction, visualization, and visualization-assisted simulation software may offer a compelling technique for assisting subalpine fir log processing decisions. However, the destructive data collection method used in this study is “error-prone”. Therefore, an interesting alternative would be the use of more accurate non-destructive scanning techniques, such as CT-scanning, for the data collection process. A new study is already underway to meet this need.

COMPRESSION WOOD IN SOFTWOODS: QUALITY CONCERNS FOR TODAY'S PULP AND PAPER INDUSTRY

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The following are covered in the paper: cause and distribution of compression wood (CW) formation in black spruce (*Picea mariana* [Mill.] BSP), chemical, physical and anatomical properties of CW, and utilization of CW in the pulp and paper industry.

Black spruce is one of the most important commercial species in Ontario with superior morphological, physical, and chemical properties suitable for various applications. However, it is known that about 15% of the wood in a typical black spruce tree consists of compression wood, which is formed on the lower side of branches and leaning trees and/or is due to the influence of wind, snow, light, or any other factor causing stem deviation from the vertical. Compression wood contains high amounts of lignin, lower cellulose, short-fibers, and generally is a relatively low quality wood for many applications.

Chemical, physical, and anatomical properties of CW are markedly different from those of normal wood. These differences will be explained and compared and their effects on pulping and papermaking will be discussed. Pulp produced from CW has 7–10% lower yield (corresponding to 2.5–3 tons of usable pulp per hectare), higher amounts of lignin and reject contents, and poorer physical and mechanical properties. During both pulping and bleaching, the consumption of chemicals and energy required to produce pulp from CW is also higher. The physical and chemical treatments to improve the quality of CW pulp are also less effective than pulp produced from normal wood. Therefore, paper made from CW pulp is of inferior quality compared to that from normal wood.

These effects can result in operational difficulties during papermaking and printing. They will have impacts on the speed of producing paper as well as printing, with machines which operate at fast speeds of 60–100 km/h with new paper machine technology in Canada. It can be concluded that the presence of compression wood in chips will eventually impact both on the quality and price of the final products. Since Canada is the largest producer and exporter of TMP pulp (newsprint) and one of the largest chemical-pulp producers in the world, our scientists should work on improvement of softwood trees and on how to prevent or decrease CW formation. These can be done through genetic manipulation of trees and/or silvicultural modification of conifer forests.

DETERMINATION OF FIBER SATURATION POINT (FSP) OF IRANIAN BEECH BY "POROUS PRESSURE PLATE" METHOD

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In this study, variations in fiber saturation point (FSP) along the longitudinal and across the radial axes of beech (*Fagus orientalis* L.) wood were investigated. To prepare specimens, two sound beech trees from the Veisar forest (Caspian natural hardwood forest in Iran) were cut. Then, 4 disks from different intervals were taken. The experiments were performed on the samples systematically taken from the four cardinal directions of each disk. To determine the FSP of un-dried samples, the "Porous Pressure Plate" method was used. The data were statistically analyzed.

The results indicated that FSP variations through the longitudinal axis do not follow a regular pattern and that they are not significantly different. Nevertheless, it was observed that samples from the first height (215 cm) had minimum value (27.1%) and the third height (555 cm) had maximum value (31.0%). The FSP variations of the four directions were not significantly different. The highest and the lowest values were found to be, respectively, on the eastern and western sides of the trees.

BREEDING RADIATA PINE TO MAXIMIZE PROFITS FOR SOLID WOOD PRODUCTS

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Current radiata pine (*Pinus radiata* D. Don) planting stocks of Southern Tree Breeding Association radiata pine members come from two generations of intensive selection and breeding. The selection criteria for the first two generations were tree growth rate (diameter and height) and form traits (stem straightness and branching quality). Selective breeding in radiata pine has brought a 30% improvement in growth rate in Australia radiata pine plantations. Breeding for growth rate and tree form has reduced wood density in radiata pine due to a negative genetic correlation (-0.30) between DBH and wood density. To maximize genetic return on profits from breeding, a major project to develop breeding objectives for radiata pine solid wood products was developed. The two major elements in the project are: 1) developing a profit equation and deriving economic weights for breeding objective traits and 2) estimating genetic parameters from selection criteria at an early age to breeding objective traits at rotation age.

We have specified a simple production system for radiata pine grower, sawmill, and integrated enterprises. Some sources of income and expenditure in several regions in Victoria State were identified. Tree biological traits influencing costs and revenues, and preliminary profit equations were also examined. Wood samples were collected from three rotation-age sites for examining age-age genetic correlations from early to rotation age. Preliminary analysis from two sites revealed that age-age correlations were site dependent.

INCORPORATING WOOD QUALITY TRAITS AND END USES INTO TREE BREEDING PROGRAMS

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During the past few decades, selection for tree growth has been the focus of most tree breeding programs. With the worldwide move in forest management to short rotations and the increasing proportion of the wood supply from improved and intensively managed plantations, wood quality has become a major concern to the forest products industry. Faced with this concern, wood quality is considered, by many, as an integral part of tree breeding programs where wood is to be the end product. To this end, numerous studies have been carried out on the genetics of wood quality in many commercial timber species around the world. To incorporate wood quality traits into tree breeding programs, however, there remain some challenges. In this paper, the major challenges are reviewed, and potential solution, and research needs are discussed.

THE PHYSIOLOGICAL AND GENETIC BASIS OF FIBRE QUALITY IN HYBRID ASPENS

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Aspen hybrids between *Populus tremula* L. and *P. tremuloides* Michx. are fast growing and have narrow diameter fibres with thin walls, ideal for producing a high-density paper sheet with a smooth surface. The main objectives of this study are to better understand the genetic control of wood physico-chemical properties in hybrid aspen, the genetic relationships of these wood properties with growth and phenological traits, and to find new and practical approaches to utilizing genetic gain. The materials used in this study comprise seven hybrid aspen clonal trials in Finland and Sweden, as well as newly propagated aspen clones in the Haapastensyrjä plant nursery. Significant differences were found in wood physio-chemical properties and also in physiological, morphological, phenological, and rooting ability among hybrid clones. Relatively high repeatabilities for wood qualities and growth traits were found. Among the physiological and morphological characters, only stomatal characters of hybrid clones differ from *P. tremula*. The high stomatal density and small mean guard cell length in *P. tremula* may be associated with the adaptation of this species to long day-length during the summer. A strong correlation was found between foliar nitrogen and net photosynthesis among the hybrid clones. This indicates that foliar nitrogen might be used to predict net photosynthesis. The fast overall growth of the aspen hybrids is largely explained by their longer vegetative growth period. This response is not true heterosis as has been commonly assumed in hybrid aspen. Annual growth rhythm is an important determinant of variations in wood physico-chemical properties. The length of growth period could be a good predictor of clone differences in fibre count. The estimated correlations were unfavorable, in the sense that clonal selection directed at increasing the fibre count is expected to produce an indirect genetic decline in growth. Inter-site genetic correlations indicated that wood characters were more stable than growth traits. A statistically significant interaction in height growth exists between aspen clones and their test sites. The ranking of clones changed across sites, indicating significant site X clone interactions in height and basal diameter. The topography (slope), soil structure, and nutrient availability are likely to be contributing to the main environmental factors interacting with genotypes. Stem cuttings were harvested from the same micropropagated donor plants twice during the growing season. A significant variation for most traits related to rooting ability was found among the clones, indicating that clonal effects play an important role in the propagation of aspen. Thus, clones with a good response in shoot growth and rooting could be exploited for large-scale propagation using stem cuttings.

GENETIC VARIATION IN DECAY RESISTANCE AND ITS CORRELATION TO WOOD DENSITY IN WHITE SPRUCE (*Picea glauca* [Moench] Voss)

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This study investigated the genetic variation of white spruce (*Picea glauca* [Moench] Voss) in decay resistance and its correlation with wood density. Three fungi were examined, a brown-rot fungus (*Gloeophyllum trabeum*), a white-rot fungus (*Tremetes versicolor*), and a standing-tree decay fungus (*Fomitopsis pinicola*). A total of 270 trees of 36 families were harvested from 36-year-old provenance-progeny trials at two sites through a thinning operation. The growth of the three fungi was evaluated using an accelerated-testing method. The narrow-sense heritability of white spruce decay resistance to brown rot and white rot was 0.21 and 0.27, respectively. There were no significant differences in the resistance to standing-tree decay fungus among the families. The narrow-sense heritability for heartwood density and mean ring width was 0.15 and 0.35, respectively. The results revealed considerable phenotypic variation and relatively high additive genetic variation in the heartwood decay resistance. The phenotypic and genetic correlations between brown rot and wood density were positive, but the genetic correlation between wood density and white rot was slightly negative. The results indicate that the different species of fungi have different relationships between growth and wood density. This suggests that selection for wood density in white spruce might lead to an increase in resistance to white rot infections, but an increase in infections to brown rot.

STEM ANALYSIS OF FAMILY VARIATION IN DENSITY AND MICROFIBRIL ANGLE OF 19-YEAR-OLD WESTERN HEMLOCK

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Disks from 3 stem heights were sampled for 6 open-pollinated families of western hemlock (*Tsuga heterophylla* [Rafn.] Sarg.) selected from 19-year-old progeny trials in coastal British Columbia. For each family, 4 trees were harvested on each of 2 sites. Microfibril angles (MFA) and wood density were measured and modulus of elasticity (MOE) estimated using Silviscan – 2. There was statistically significant variation in MFA and MOE from one site to the other, but not for density. As is often found, diameter growth and wood density, for individual samples, were significantly negatively correlated. The correlation for diameter with MFA was of similar magnitude but not adverse. Perhaps as a consequence of these trends offsetting each other, predicting family ranks of the upper bole positions using the lower sample (from breast height) was more successful for MOE relative to either of the contributing influences of MFA or wood density.

POSTER ABSTRACTS

INDUCED FLOWERING IN ASPEN

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A trial to investigate flower induction in a grafted, potted aspen (*Populus tremuloides* Michx.) orchard was carried out in 2001. The objective was to test different methods of flower induction in grafted aspen grown in pots. The ultimate goal is to obtain an effective, reliable, and safe treatment for flower induction to allow for a controlled crossing program using selected parents.

Soil drenches with two early stage inhibitors of gibberellin (GA) biosynthesis, the triazole Paclobutrazol (5 rates) and 2-chloroethyltrimethyl-ammonium chloride (CCC) (2 rates), and foliage spraying with CCC (2 rates) were applied in May/June 2001. Paclobutrazol and CCC were used because they have been shown to lower the levels of growth-effector gibberellins and induce flowering in other woody angiosperms. The numbers of vegetative and reproductive buds per tree were counted in the fall of 2001. Flowering was expressed on a per tree basis as the proportion of flower buds relative to the number of total lateral buds (floral + vegetative). Data were transformed using a standard arcsine transformation prior to analysis of variance to identify differences attributable to sex, treatment, and sex X treatment interaction.

All Paclobutrazol treatments and the spray CCC treatment at high dosage (1 000 ppm) induced flowering to levels significantly above those in untreated controls. The Paclobutrazol treatments were more likely to induce flowering than the CCC treatments. There were no statistically significant sex X treatment interactions i.e., treatments were equally effective in male and female trees.

It appears that flower induction using Paclobutrazol as a root drench and CCC as a foliar spray are viable methods for increasing the number of flowers in potted, grafted aspen. Germination and early seedling growth tests using seed generated from these crosses will be conducted as a final test of these induction methods.

WHITE SPRUCE PROVENANCE TRIALS AS INDICATORS FOR ASSESSING THE IMPACTS OF CLIMATE CHANGE

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Fifteen range-wide white spruce (*Picea glauca* [Moench] Voss) provenance trials were jointly established in Ontario in the late 1970's and early 1980's by the Canadian Forest Service (CFS) and Ontario Ministry of Natural Resources (OMNR). All of the sites were remeasured in the summer of 2001 to better understand the pattern of white spruce adaptive variation, the possible implications of climate change on its distribution, and the potential for seed source movement in current and future reforestation efforts. An additional 3 sites each had been installed in both Nova Scotia and Maine during the same period and were previously measured.

Provenance differentiation varied greatly across the 21 test locations. Quadratic site transfer functions and population response functions were calculated based on monthly climatic values. Transfer functions explained up to 60 percent of the observed variation and differed according to test location, while population response functions accounted for up to 90 percent of observed variation. Modeled patterns of predicted seed source 'optimal' growth and climate values showed seasonably-variable geographic trends.

10-YEAR RESULTS OF NORWAY SPRUCE PROGENY TESTS IN THE APPALACHIAN BREEDING ZONE IN QUÉBEC

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In 1989, Québec was subdivided into three breeding zones for Norway spruce. For each breeding zone, 10 superior provenances have been recommended for reforestation. To validate these zones and to increase the genetic basis of the breeding population, a series of genecological tests was planned and established in each breeding zone.

For the Appalachian breeding zone, an open-pollinated progeny test was established in 1992 in each of the three forest associations of the region. Each test is composed of 266 progenies (33 provenances) and three control provenances. At age 10, in spite of significant provenance X site and progeny X site interactions, some of them present high stability over the three locations tested. The provenances Auce and Suwalki, Poland which are recommended provenances, exhibited a height superiority of 3.6% when compared to the three control provenances. In the sole test with a high ratio of white pine weevil, two provenances originating from Hudson Place, Ontario and known as resistant provenances, demonstrated a significantly lower weevil infestation rate and superior height. For the three locations, the genetic gain for height varied from 7 to 13% for the best 26 families. For breeding values and mean height, the correlation between five-year and ten-year results is more then 82%. Trees will be selected for inclusion in the breeding population and for establishing new seed orchards. The results obtained emphasize the potential of tree improvement for this exotic species.

EFFECTS OF THE WHITE PINE WEEVIL ON THE TIMBER QUALITY OF SELECTED PROVENANCES OF NORWAY SPRUCE IN QUÉBEC

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Although it has been demonstrated that white pine weevil (*Pissodes strobi* Peck.) attacks do not affect the long-term productivity of Norway spruce (*Picea abies* [L.] Karst.) stands, foresters are concerned about the timber quality obtainable from these stands. In response to these concerns, a study was carried out on the quality of timber from a provenance test planted in 1969. The study was done using randomly chosen trees from a selective thinning and from six recommended provenances. The trees were divided into three classes according to the number of major crooks or forks caused by weevil attacks on their stems. Stem quality classes 1, 2, and 3 refer to trees with zero, one, and two or more major defects, respectively. In some years, the weevil infestation rate in the provenance test was more than 35%. Trees from a stand of white spruce (*Picea glauca* [Moench] Voss) of similar age and located on the same site were used as controls. For the study, 150 trees, including 40 white spruce, were cut down, measured, bucked into 8-foot logs, and taken to the sawmill. After drying, the wood was graded according to the classification standards in effect in Canada. In comparison with the control species, the results show that for Norway spruce: 1) on average, the volume of logs delivered to the sawmill is similar, despite distortions caused by the weevil, 2) the yield in foot-board measure is 5% higher for stem qualities 1 and 2, and similar for stem quality No. 3, and 3) on average, the proportion of stock graded *Select structural* or *#1* is higher. In conclusion, Norway spruce can correct many distortions caused by the weevil and has a high potential for producing quality timber. Its total productivity will not be greatly affected by the weevil.

LONG-TERM STORAGE POTENTIAL OF SEED FROM FOUR SPECIES OF SPRUCE

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The National Tree Seed Centre has been storing and providing seed for research for over 35 years. During this time germination test data have accumulated which can provide an indication of the long-term storage ability of seed. Storage temperature and seed moisture content are the two most important factors affecting seed storability with the general recommendation that temperature be about -20°C and moisture content be 5-8%. Data from *Picea glauca* (Moench) Voss, *P. mariana* (Mill.) BSP, *P. rubens* Sarg., and *P. sitchensis* (Bong.) Carr. were evaluated. Seed of these species was stored at -20°C with moisture content ranging between 3.8 and 9.8%. In order to assess storage potential, seed lots with germination above threshold limits were chosen. The threshold limits decreased with increasing age to reflect a general decrease in germination with age. Whenever possible, mean germination was calculated for each year. A curve representing these 'best seed lots" was fitted through the data points for each species. This curve does not represent the maximum storage potential as data from seed lots which have been taken in and out of storage for numerous reasons were used. For *P. glauca*, germination was maintained above 95% for the first 20 years but thereafter exhibited a steady decline to about 75% at 33 years. Germination of *P. mariana* remained above 95% for 25 years. *P. rubens* seed showed a slow but steady decline in germination to just over 80% at 36 years. Germination remained constant at above 90% for 15 years for *P. sitchensis* seed but declined slowly to just over 80% at 31 years. The potential for long-term storage is further strengthened by considering germination of a selected old, best quality seed lot of each species: *P. glauca* age 33 years, germination 91.5%; *P. mariana* age 30 years, germination 94.5%; *P. rubens* age 45 years, germination 79.5%; and *P. sitchensis* age 31 years, germination 91.5%. These results indicate that good quality seed of these species, stored under the proper conditions, could retain functional viability above 60% for up to 100 years.

TRYPTAMINE ACCUMULATION IN TRANSGENIC POPLAR AND TOBACCO REDUCES INSECT PREDATION

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The enzyme, tryptophan decarboxylase (TDC) converts tryptophan to tryptamine, a neuroactive substance that may affect insect behavior, development, and physiology. To examine the feasibility of improving pest tolerance by modifying tryptamine levels, explants from the hybrid poplar clone *Populus tremula X P. alba* INRA 717 and tobacco *Nicotiana tabacum* were transformed with a *TDC1* cDNA driven by the CaMV35S promoter. Putative transgenic lines were confirmed by PCR detection of the presence of the *TDC1* gene sequence, and by expression analysis of the transgene mRNA and encoded protein. Chemical and radiotracer analysis suggested that the major accumulated product of tryptophan decarboxylation was tryptamine. No visible phenotypic changes were associated with ectopic TDC expression in either species. Plants from the high, medium, and low expression groups were selected for insect bioassays using *Malacosoma disstria* (forest tent caterpillar) and *Manduca sexta* (tobacco horn-worm) on poplar and tobacco, respectively. In both interactions, larvae consumed significantly more leaf tissue and gained more weight on the foliage of plants with low *TDC1* gene expression in comparison to the foliage of plants with high *TDC1* gene expression and higher levels of tryptamine. This suggests that ectopic expression of *TDC* can allow sufficient tryptamine to accumulate in poplar and tobacco leaf tissue to deter predation by specific herbivorous insect pests.

FIRST STEPS IN UNPACKING THE POPLAR GENOME

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Poplar has been widely accepted among plant biologists as the "model tree" for studies of the molecular basis of traits unique to woody perennials. Three poplar genomics projects currently underway in Canada (Treenomix), the USA (USDA, DOE), and Sweden (Swetree) should now revolutionize our understanding of the genes involved, their regulation, and the functional connections between genes and tree phenotype. By 2003, collections of poplar gene sequences should reach >150 000 ESTs, large-scale DNA microarrays should be available for assessment of gene expression profiles, and the full genome of *P. trichocarpa* should be shotgun sequenced to 6X coverage. In our first steps towards unpacking and understanding the poplar genome, we have, together with the Genome Sciences Centre in Vancouver, fully fingerprinted a *P. trichocarpa* BAC library of ~48 000 clones and designed a tiling path of BAC clones consisting of roughly 1000 contigs for use in conjunction with the DOE shotgun sequencing. In addition, 84 942 quality BAC end-sequences (both 5' and 3') have been obtained, representing an initial survey of ~10% of the genome. These paired end sequences and a proposed collection of phosmid paired end sequences should help with whole genome assembly. Within our BAC end sequences, we found 1 455 SSRs of at least 24 base pairs. The structure of longer repeats and the types of transposable elements are now being identified. SNP (single nucleotide polymorphism) discovery will begin shortly. When combined with the development of large pedigree populations, this high-density of SSR and SNP markers will make it possible to link genotype with phenotype at an unprecedented level of resolution.

VALIDATION OF THE IDENTITY OF PARENTS USED IN DETERMINING GENE FLOW AMONG *Populus* SPECIES EMPLOYING DNA MARKERS

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We have employed highly informative microsatellite (simple sequence repeats, SSR) DNA markers to determine the identity of *Populus* clones used in studying the extent of gene flow among adjacent trees. The primer pairs amplified defined specific regions of the genomic DNA and, by virtue of their allelic richness, could distinguish between the clones. Based on the multilocus genetic structure employing 12 loci, one clone of unknown origin (Daniels) was determined to be Northwest. Similarly, one clone (Hubert) presumed to be Griffen was determined to have been misidentified, and was in fact Brooks-6. On the other hand, one clone at ALPAC mill site (#37, Pchey) putatively identified as Brooks-6 turned out to be Griffen, as was the case with another clone (#36D). An unknown male (Whelden) was determined to be Brooks-6 using the same criteria. One clone (Lamoreux Road), tentatively identified previously as either Brooks-6 or Northwest, was determined to be Northwest in the current study. We were unable to identify a clone growing at ALPAC mill site (*P. petrowskyana* / Dunlop x Brooks-6, #51) possibly due to its putative complex background. The identity of the other 23 clones turned out be the same as their labels. We are currently using the progeny derived from controlled crosses and open pollination, utilizing some of these clones employing these SSR markers, to determine the possible and the actual extent of gene flow among the clones. We are also attempting to identify species specific SSR alleles that would enable us to determine the extent of gene flow among these clones.

DEVELOPMENT OF A CONSERVATION STRATEGY FOR DWARF BIRCH (*Betula glandulosa* Michx.): EVALUATION OF SEED GERMINATION

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Dwarf birch (*Betula glandulosa* Michx.) is a subalpine species which occurs in southern areas only at high elevations. It has been identified as a species of concern in New Brunswick (NB), since it is extremely rare in the province and current knowledge pertaining to its health is inadequate. One NB population has been identified at Big Bald Mountain. This study examined the germinability and quality of seed collected from 30 shrubs at Big Bald Mountain. The population was divided into three sites, 10 shrubs/site; one exposed (E-1) and two protected (P-1, P-2). An alcohol separation was done to divide seed into two fractions, one containing primarily full seed and the other containing empty seed. For the full seed fraction, germination at E-1 ranged between 45 and 97% with a mean germination of 73%, at P-1 germination ranged between 38 and 90% with a mean germination of 68%, and at P-2 germination ranged between 62 and 88% with a mean germination of 84%. Mean gemination time (MGT) at E-1 ranged between 5.39 and 6.31 days with an average MGT of 5.70 days, at P-1 MTG ranged between 5.48 and 6.73 days with an average MGT of 6.01 days, and at P-2 MGT ranged between 5.48 and 6.73 days with an average MGT time of 6.01 days. X-ray analysis was conducted on the full seed and seed was scored as filled, poorly developed, or empty. Results of the study suggest that there are site differences in the amount of full seed in seed lots of comparable total seed weight.

SAMPLING STRATEGIES FOR CAPTURE OF DIVERSITY AND CONSERVATION OF RARE ALLELES

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Rare alleles are often considered a minor element in gene conservation programs and yet they can be very important for long-term evolution. For example, if low frequency alleles become a target for future breeding objectives or for survival of wild populations, the possibility of relatedness among selected or surviving genotypes may not allow effective use of these low-frequency alleles due to an excessive build-up of inbreeding. It is therefore desirable to raise the probability of maintaining rare alleles in enough unrelated genotypes for future use in wild or breeding populations.

Useful empirical and experimental data for developing species sampling strategies for conservation of rare alleles is limited in availability. There is a lack of knowledge as to which population structure (i.e., continuous or disjunct distribution) is likely to harbour rare alleles. Strategies for collection of seed are much more flexible than the design of *in-situ* reserves and can be designed to maximize the capture of genetic diversity across the landscape, particularly rare alleles. This work focuses on sampling strategies for conservation of rare alleles through a study of the distribution of rare alleles at different spatial scales, using Sitka spruce (Picea sitchensis [Bong.] Carr.) as a model species.

A STUDY OF ADAPTATION AND GENE FLOW IN PERIPHERAL POPULATIONS OF SITKA SPRUCE

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Loss of biodiversity due to lack of sufficiently rapid adaptation to rapidly changing environments are serious global concerns for natural resource production and conservation. Understanding evolutionary population dynamics and a species' ability to adapt to local environments can be useful for predicting future population dynamics and identifying unique genetic resources. Long-term population dynamics and spatial and temporal distributions across environments depend on a balance among selection intensity, gene flow, and genetic drift. Adaptation to local environments by peripheral populations may be limited by gene flow from core populations at the center of population density. Isolation limiting gene flow could lead to rapid local adaptation if population sizes are adequate.

Sitka spruce (*Picea sitchensis* [Bong.] Carr.) has a long and narrow distribution along the Pacific Coast from northern California to Alaska. Since northern parts of North America were largely glaciated during the last Pleistocene glacial period, Sitka spruce has rapidly extended or shifted its range during the subsequent postglacial period. This species could give us a good picture of the relationship between gene flow and adaptation and of historical dynamics. The adaptation rate of populations in similar climates but with different levels of gene flow will be studied to determine the degree to which gene flow limits adaptation, and thus range expansion of a species. Our major objective is to understand the roles of gene flow in the adaptation and evolution of a species' range, using Sitka spruce as a model species. Specific interests are: 1) the tradeoff between gene flow and adaptation in response to environmental gradients, 2) the force of directional gene flow, and 3) the historical dynamics and range expansion of Sitka spruce during the last deglaciation. We will approach these issues using analyses of both genetic markers and quantitative traits for the assessment of gene flow and adaptation, respectively.

GENETIC GAIN OF BLACK SPRUCE IN NEW BRUNSWICK

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The New Brunswick Tree Improvement Council (NBTIC) recently completed the measurement of several series of 20-year old black spruce family tests and stand tests. Each series was measured at 5 year intervals for height, damage, and dbh (after age 15). To compare the first generation material with that of unimproved material, the top-ranked 25% of families in the family tests represented improved material and the stand tests represented the unimproved. The data were entered into the STAMEN Stand Growth Model, stand tables created, and merchantable volume was calculated. STAMEN is a computer model used in New Brunswick for developing yield curves.

At age 40, the projected merchantable volume of the top 25% of first generation black spruce is 11% greater than the stand test material. This estimate is conservative as the current model of STAMEN is calibrated based on slower-growing, unimproved trees from wild stands. Genetic gain estimates from 10-year-old second generation progeny tests were also compared to first generation material and stand tests. A direct comparison of measured height was used, as trees in second generation tests are not old enough to measure diameter. Estimates from this comparison suggest that a further 10% volume gain of the second generation over the first generation appears to be easily attainable, and once again, quite conservative.

GENETIC DIVERSITY AND BREEDING ADVANCE IN HAWAII'S *Acacia koa*

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Acacia koa Gray is Hawaii's primary timber tree. This tetraploid legume is endemic, widespread, and evidently ancient in the Islands. We have planted half-sib family trials of koa annually since 1990. Growth is rapid, to 50 ft. in 6 years, and extremely variable among families. All of the ~750 families have been planted at our Hamakua Research Station, 2 100 ft. elevation. Selected progenies also are being evaluated at other locations. Mortality has been high and is largely ascribed to koa wilt (*Fusarium oxysporum*), the subject of a workshop in June 2002 and of a forthcoming University of Hawaii publication. Wilt appears to be the primary factor limiting koa to high elevations (> 2 000 ft) in the islands. Flowering is observed within four years and two seed orchards have been established as composites of seed from outstanding progenies. Estimates will be presented for genetic diversity and rates of genetic gain for wilt tolerance and for growth rate, forking, bole form, rust resistance and other traits. Few data are yet available on wood quality and notably on the highly prized fiddleback figure. Vegetative propagation has been refractive in koa until recently, when X. Shi was able to achieve clones under mist from greenhouse-grown trees. Clones are being planted in G X E trials and methodology extended to root sprouts of superior field-grown trees. As a plantation tree, we predict that superior koa composites, clones, and hybrids will be harvestable in 20 years.

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