Controlled Parentage Program Plan for the Region G2 White Spruce Tree Improvement Project in the Northwest Boreal Region in Alberta

Technical Report

August, 2008

Example only

Alberta Tree Improvement and Seed Centre
Alberta Sustainable Resource Development
Smoky Lake, Alberta T0A 3C0

For further information regarding this report, please contact:

Alberta Tree Improvement & Seed Centre
Alberta Sustainable Resource Development
Smoky Lake, Alberta T0A 3C0
Phone: (780) 656-5072

NOTE: This report is one of a series of Controlled Parentage Program Plans being developed by the Alberta Tree Improvement & Seed Centre. These reports generally follow a standard format and where applicable, may contain duplicate information.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

Tree improvement through selection and breeding has a long history in Canada. The earliest tree improvement programs date back to the 1950's. In Alberta, tree improvement was started in 1975. Despite modern advances in biotechnology and their widespread applications in crop breeding, tree breeding programs have remained largely conventional using traditional plant breeding methods for selection, breeding and improved seed production. Forest trees are long-lived perennial plants and have life cycles that invariably span many decades to several centuries. As a result, progress is often relatively slow and time demanding. Project development and completion timelines are often long (30 years and over) and many years may pass before any practical benefits are realized. Because of the long timelines, project plans need to have built in flexibility to accommodate changes in objectives and methodology over a period of time and reasonable assurances must exist for project continuity and quality control through completion of various project phases.

White spruce (*Picea glauca* [Moench] Voss) is one of the most important commercial forestry species in Alberta. Approximately 43 million white spruce trees are planted each year to regenerate harvested and denuded areas. The species is a dominant component of the Boreal and Foothills Natural regions in Alberta and a significant component of the Parklands and Rocky Mountain Natural regions. There are nine white spruce breeding regions delineated in Alberta at present and each breeding region corresponds to a separate white spruce genetic improvement project.

This report describes the breeding plan or Controlled Parentage Program Plan (CPP) for genetic improvement of white spruce in Breeding Region G2 located in the northwest boreal region of Alberta (Figure 1). This project was started in 1995 and the CPP was written in 2007 - 2008 and it consolidates various documentation and information regarding the project in one place to meet current Standards for Tree Improvement in Alberta (STIA) guidelines (ASRD 2005). It should be recognized that some elements of the established project require explanation or remedies (e.g. inclusion, in the breeding population, of some 'non-native' parents from the B.C. area adjacent to the breeding region.) to conform to the STIA guidelines which were established well after this project began. These issues are identified in appropriate sections and rationale or remedies for these are discussed. Also, the G2 breeding program is low intensity with a moderate expectation of genetic gain which provides added flexibility in adjusting technical plans. For example, retention of a large number of parents in the existing orchard provides the opportunity for bringing the program in alignment with STIA.

2.0 PROJECT HISTORY

The Breeding Region G2 white spruce project is derived from the earlier Region G1 white spruce project in west central Alberta. The G1 project concept was modified around 1990 to exclude the northern area, mainly the Peace region, which was a provisional reserve for the proposed FMA expansion of Procter and Gamble Cellulose, Ltd (now Weyerhaeuser, Grande Prairie). The FMA expansion proposal was not successful and, as a result, the provisional reserve area was opened for other development proposals. Under this process, Manning Diversified Forest Products (MDFP) was a successful bidder. The G2 project was initiated at the request of MDFP in 1995 as a cooperative project with a major part of the funding provided by the MDFP Research Trust Fund. Other forest industries in the area were contacted for participation in the project. Canadian Forest Products (Hines Creek) and Daishowa-Marubeni initially agreed to participate in the project but after a few years both companies withdrew due to business reasons. Fairview College also participated in the project for a few years (1996 - 1998) with the interest that some of the project activities (mainly seed orchard management) might provide opportunities for student learning and summer employment. Fairview College also withdrew from the project in 1999 after a management program review and policy change. However, during these changes, the project work continued relatively unaffected because the project was led by the Alberta Tree Improvement & Seed Centre (ATISC) supported by MDFP Research Trust Fund funding and a strong commitment by MDFP. Interim work program adjustments were made during this period and new partnerships developed which included Tolko Industries, High Level and the North Peace Applied Research Association (NPARA). In 2005, the Forest Genetics Alberta Association (FGAA) was formed and joined in as a new cooperator to provide program coordination and carry out several project activities on behalf of the project partners.

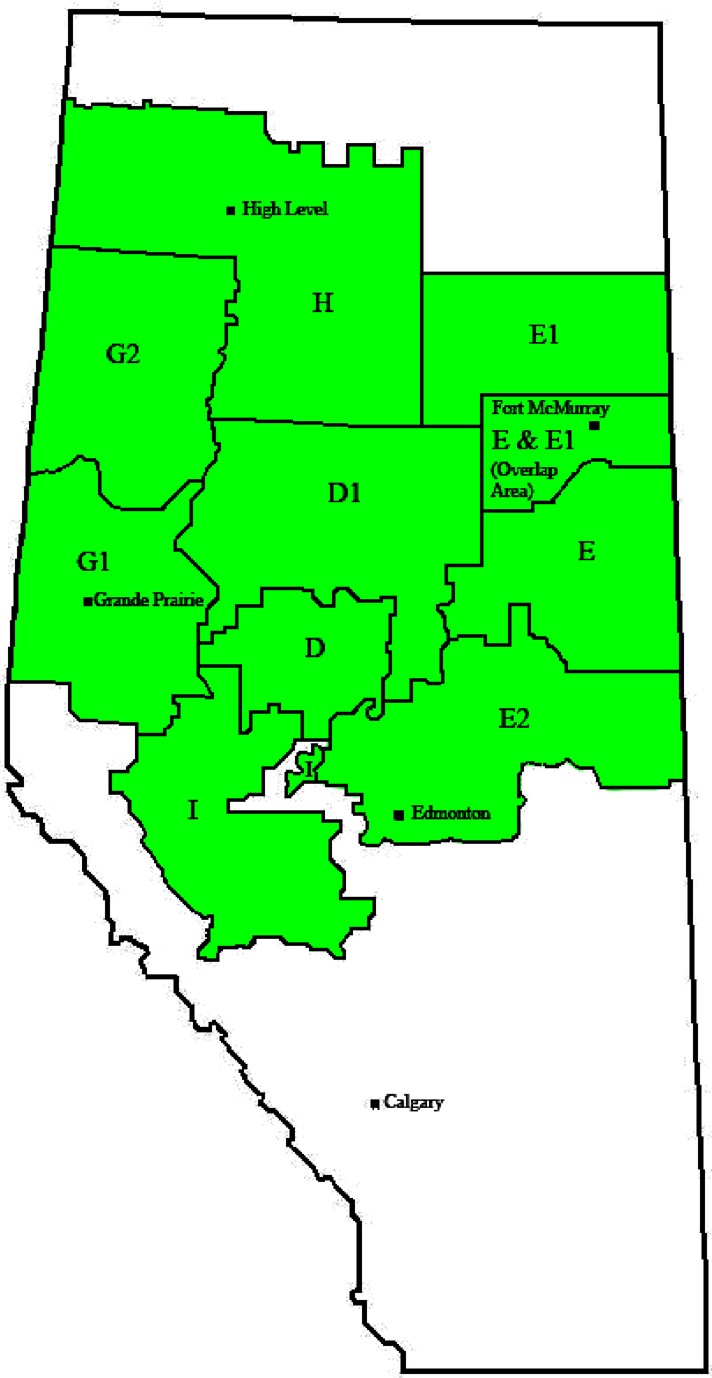


Fig. 1 White spruce breeding regions in Alberta.

NOTE: Breeding region boundaries are generalized in this figure and are not exactly as shown.

3.0 COOPERATORS

At present (2008), the project has three partners as listed below along with their share in the project.

- Manning Diversified Forest Products Ltd (MDFP) - 72%
- Alberta Tree Improvement & Seed Centre (ATISC) - 24%
- Tolko Industries High Level (TIHL) - 4%

The project partners are the 'owners' of the project and are responsible for project operations and costs. A formal agreement defining the ownership rights, roles, responsibilities and obligations of the partners is under development.

In addition, Manning Forestry Research Fund (formerly Manning Forestry Development Research Trust Fund) participates in the project by providing annual funding to ATISC (currently in its 11^{th} year of renewal) for research, technology transfer and conservation aspects of the project. NPARA participates in the project through contract delivery of some technical services to the project and leasing land at its farm in North Star for the seed orchard.

There is also a cooperative arrangement with the B.C. Ministry of Forests and Range (BCMoFR) which links the work in the G2 project with the white spruce project in the adjoining Peace Plateau area of northeastern British Columbia through exchange of genetic stock, scientific information, and cooperative genetic testing and research.

4.0 ECOLOGY AND GENETICS OF WHITE SPRUCE

4.1 Ecology and Reproduction

White spruce has a wide and continuous natural range across the North American boreal forest from Newfoundland to the Bering Sea in Alaska and from 44^{o}N in Wyoming and South Dakota to 69^{o}N in the Arctic. Its elevation range extends mainly from sea level to 1520 metres (Nienstaedt and Zasada 1990) but the species can also be found at much higher elevations in the Rocky Mountains of western Canada. In Alberta, it is one of the most abundant and widely distributed tree species. It has nearly continuous distribution in the boreal forest in northern Alberta. The southern limit of its distribution in the province varies from east to west: starting in the east, its natural distribution limit is a few kilometers north of Lloydminster; the southern limit then veers southwest, with spurs along the Battle, Red Deer, and Bow Rivers; it then extends west from Calgary and along the foothills of the Rocky Mountains. In addition, a substantial outlier or 'island' forest of white spruce occurs in the Cypress Hills in the southeast corner of Alberta. At higher elevations (1200 – 1800 m) in the foothills, white spruce hybridizes with Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) forming a hybrid complex, which eventually gives way to pure Engelmann spruce forest types at the highest elevations. As the climate becomes more severe at higher latitudes in the boreal forest in northern Alberta, white spruce is increasingly replaced by black spruce on many sites. The best development for white spruce occurs on loam to clay loam alluvial or lacustrine deposits and in water discharge areas where well-aerated water and adequate nutrients are available. It is well-adapted to boreal areas with a continental climate (warm summers and cold winters), but is also quite plastic in its ability to tolerate extremes of both climate and soil conditions.

White spruce is moderately shade tolerant and can behave either as a pioneer species in disturbed habitats or as a climax species following aspen in mixed stands. It is common in mixtures with aspen (*Populus tremuloides* Michx), balsam poplar (*Populus balsamifera* L.), black spruce (*Picea mariana* [P. Mill.] B.S.P.) and lodgepole pine (*Pinus contorta* Dougl.) and, to a lesser extent, with white birch (*Betula papyrifera* Marshall) and Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) in early- to mid- succession stands of boreal, foothills and montane forests. In mid- to late- succession stands, it may form pure stands or occur with components of black spruce and balsam fir (*Abies balsamea:* [L.] Miller). In the Parklands, it is often limited to north facing slopes and small populations on moister sites along the southern and eastern edge of its range.

White spruce is a monoecious species. Reproductive bud differentiation occurs in the year prior to flowering and is enhanced by hot dry weather at the time of differentiation. Female flowers tend to be distributed in the upper crown and male flowers are more common in the lower crown. Pollination occurs in the spring followed by fertilization in 2 - 3 weeks. After fertilization, cones develop rapidly and embryo development is usually complete by early to late August, but timing can vary by several weeks from year to year depending on the seasonal weather. Cone ripening and seed release occurs in late August to early September. Mature seed is winged and wind dispersed but seed loading falls dramatically with distance from the source. White spruce seed shows conditional dormancy and does not germinate readily below 10^{o}C.

Although individual trees in natural stands may produce seed as early as ten years of age, good seed production generally starts around 30 years of age. Seed production is periodic with good crops occurring every 2 – 6 years where the climate is favorable. The quantity, quality and periodicity of seed crops are highly dependent on climate and weather. At high elevations and latitudes, the periodicity of good crops may be 10 – 12 years due to cool growing seasons, which disrupt pollination and retard and damage embryo development. Good yielding seed crops are generally of better quality than poor crops. White spruce reproduces naturally only by seed and dispersal is mainly by wind. Seedbed moisture is the most important factor in establishment from seed but dense growth of competing vegetation on the seedbed is also an important factor.

Harvest rotation age for white spruce forests in Alberta is generally in the range of 90 – 120 years. Reforestation is most commonly achieved by planting. White spruce is also an important species for wildlife habitat, especially for providing thermal shelter during winter, and its seeds are an important source of food for many species of birds and squirrels.

A good review on the silviculture and ecology of white spruce is provided by Nienstaedt and Zasada (1990).

4.2 Genetics and Tree Breeding

The extensive latitudinal and elevation range of white spruce suggests that a considerable amount of genetic variation exists within the species. In the research paper titled “The Genetics of White Spruce”, Nienstaedt and Teich (1971) provided an extensive review of the reproduction, genetics and evolution of white spruce. In this section, we provide (i) a brief review of the range-wide genetic variation of white spruce in Canada based on studies conducted outside Alberta, (ii) preliminary results of variation among Canadian provenances based on provenance tests performed in Alberta, (iii) extensive results and synthesis of white spruce genetic variation within Alberta, and (iv) evaluation of the suitability of selected parent trees for specific regional white spruce breeding programs in Alberta (in this case G2). Progeny studies established to support individual breeding programs are also briefly reviewed. Emphasis is given growth potential, climatic-related genetic adaptations and resistance to white pine weevil (*Pissodes strobi* (Peck).

4.2.1 Range-wide Genetic Variation

Provenance studies have shown that white spruce exhibits high genetic variation among populations. In the eastern part of its natural range, white spruce provenances with highest growth potential occur in southeastern Ontario (e.g., Teich et al. 1975; Stellrecht et al. 1974; Li et al. 1997; Tebbetts 1981) and generally, growth potential declines with an increase in latitude (e.g., Khalil 1986; Hall 1986; Nienstaedt and Riemenschneider 1985) and longitude (Furnier et al. 1991) of seed origin. In 1982, the Alberta Forest Service established a field trial (G103RW) at Calling Lake (55^{o}17’ N; 113^{o}09’ W and 625 m) as part of the Canada range-wide provenance trial series 410. It has a randomized complete block design with 5 replications, 43 provenances and 5-tree row plots and 2.5 × 2.5 metre (m) spacing. Seed source origins are described in Appendix I. This study shows that at 24 years from seeds, height (H24) was related to latitude (R^2 = 0.45) and longitude (R^2 = 0.76) of seed origin (unpublished data). Figure 2 shows that growth potential generally declined from central Canada (Ontario, Quebec and Manitoba) to British Columbia and Yukon. Provenances from Newfoundland also exhibited relatively low growth potential.

While the growth trend depicted in Figure 2 partly supports a westward decline in growth potential, provenances from the eastern part of the natural range originated mainly at low elevation (< 400 m) and low latitudes (< 50^o N), whereas provenances from the western part of the range originated mainly from intermediate elevations (500 – 1000 m) and intermediate to high latitudes (54 – 66^o N). The Pearson's correlation between H24 and longitude of seed origin was -0.52 ($P < 0.0001$), whereas the partial correlation between the two variables while controlling latitude of seed origin was 0.01. Likewise, the correlation between H24 and provenance latitude was -0.62, whereas the partial correlation between the two variables while controlling longitude was -0.40. Thus, the observed westward decline in growth potential (Figure 2) is simply a direct consequence of the northward decline in growth potential. The correlation between H24 and provenance elevation was -0.22. Because of the westward increase in both latitude and elevation for the tested provenances, the correlation between H24 and provenance latitude is partly due to a decline in growth potential both from south to north and from low to high elevation. Indirectly, controlling provenance longitude removes an elevation effect leading to a low partial correlation between H24 and provenance latitude.

Many exotic provenances grew better at the Calling Lake site than Alberta provenances, which are planted in either G103RW or G103H or both. However, to provide a measure of practical superiority of exotic over local provenances, five Alberta provenances that are closest to the Calling Lake site in terms of both latitude and elevation were selected. These provenances (0012, 0014, 0017, 0020 and 0027) from Lac La Biche, Slave Lake and Grande Prairie area (Appendix II) are collectively referred to as a regional local population. The BLUP means of these provenances from both G103RW and G103H were then averaged to obtain the mean H24 for the "local population". The mean H24 for this local population was 5.97 ± 0.28. Provenances that exceeded the mean of the local population by more than two standard errors in order of their performance were Gold Creek (Manitoba), Angle Inlet (Manitoba), Burt Twp (Ontario), Daserat (Quebec), Candle Lake (Saskatchewan) and Kapuskasing (Ontario) and are described in Appendix I. The mean heights of these provenances ranged from 6.55 ± 0.33 m (Kapuskasing) to 7.06 ± 0.32 m (Gold Creek). The fact that some of southern provenances grew better than the local population shows that the potential exists for a reasonable northward transfer of provenances to improve growth under current climatic conditions.

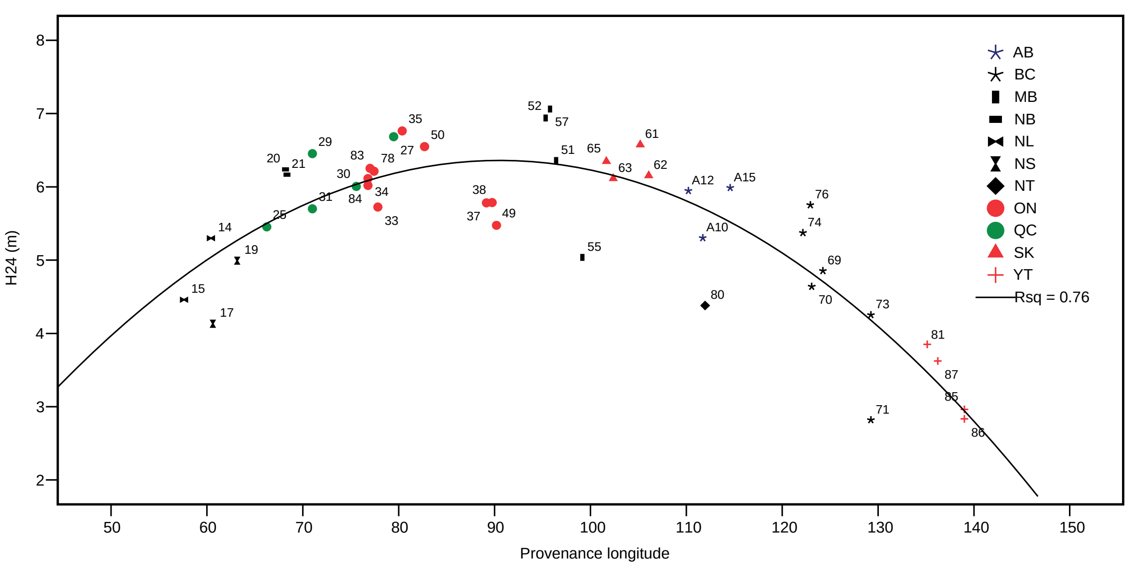


Fig. 2 Provenance height growth potential as related to longitude of seed origin in G103RW.

Data labels are provenance IDs found in Appendix I. Earlier results of the G103RW prompted establishment of two follow-up studies, namely series G276 with four sites and G277 with two sites. The G277A trial at Chinchaga River (57°47' N; 118°12' W; 500 m) is a replicated range- wide provenance study comprised of white spruce provenances from across Canada, except Newfoundland, New Brunswick, Nova Scotia and the Northwest Territory. It has a randomized, complete-block design with 5 replications, 8-tree row plots and 2.5 × 2.5 m spacing. It contains 40 provenances (mainly from Ontario and Manitoba) of which 4 are from Alberta (Appendix I). A similar but unreplicated trial is the G277B trial at Whitecourt Mountain (54°03' N; 115°47' W; 823 m), which contains 30 provenances all from outside Alberta (Appendix I). It has 8-tree row plots and 2.5 × 2.5 m spacing. Both trials contain provenances found in the G103RW trial and additional provenances from regions in Ontario and Manitoba that are considered potential sources of superior provenances for Alberta based on early results from the G103RW trial.

In the G277A trial, 15-year height (H15) of provenance 37 from Caramat, Ontario (49°36' N; 89°09' W; 305 m), exceeded height of the local provenance A21 (57°36' W; 117°31' W; 460 m) by 5%. It exceeded H15 of the other three Alberta provenances by 21 – 25%. Figure 3 illustrates the pattern of variation in height growth potential which shows that many provenances from central Canada did better than Alberta provenances at the Chinchaga site. Growth potential was related to longitude (R^2 = 0.21; $P < 0.05$) and latitude (R^2 = 0.22; $P < 0.05$) of seed origin, although the strengths of the regressions were weaker than that observed for 24-year height in the G103RW trial (Figure 3).

In the G277B, growth potential was related to longitude (R^2 = 0.36; $P < 0.01$) latitude (R^2 = 0.39; $P < 0.01$) and elevation (R^2 = 0.25; $P < 0.05$) of seed origin. The relationship between height growth potential and longitude of seed origin is illustrated in Figure 4.

A subset of provenances from selected regions in Manitoba, Ontario and Quebec, which was tested in G103RW and G277 trials, has also been tested in the G276 trials alongside selected Alberta provenances (Appendix I). This series contains 12 exotic (non-Alberta) provenances most of which are planted on all four sites and 11 Alberta provenances, which includes a regionally local provenance. Preliminary analysis of these trials has been undertaken to test the performance of the local provenances relative to exotic ones. Because the choice of provenances for testing in G276 was based on ATISC interest in those regions as potential sources of superior provenances for Alberta, the provenance effect was considered a fixed effect. Provenance least square means are summarized in Table 1 where provenances closest to the test site (regional local) are identified by bold font.

Site A is an abandoned hay field, which is reflected in its low productivity (H15) compared to site B and C that occur in a similar latitudinal zone. Except for provenance 2 from further north, the local and other Alberta provenances had among the lowest growth potential at this site. At site B, local provenances were outgrown by most of the exotic provenances. At site C, only four exotic provenances grew better than the local one but only by a limited margin (Table 1). At a high elevation site D, the local provenance was among the four best.

As previously mentioned, some of provenances from central Canada, especially Ontario and eastern Manitoba close to the Ontario border appear to be well adapted in Alberta in terms of growth potential. Although these provenances are from low latitudes and low elevations, they appear to do well at intermediate latitudes and elevations in Alberta. Because planting these provenances further north and at much higher elevations has a risk for frost and winter-related damages, further analysis will be made to assess the susceptibility of these provenances to climatic-related damages using tree condition codes recorded at the time of height measurements In addition, assessing these provenances for cold tolerance using standard methods such as whole plant and/or detached shoot freezing tests (e.g., Burr et al. 1990) may be conducted, especially when operational use of exotic provenances becomes an option. In addition, low latitudes provenances from central Canada inhabit a moister environment than most parts of Alberta. Therefore, their drought tolerance must be assessed before seed transfer into the Alberta Dry Mixedwood and portions of the Central Mixedwood can be considered.

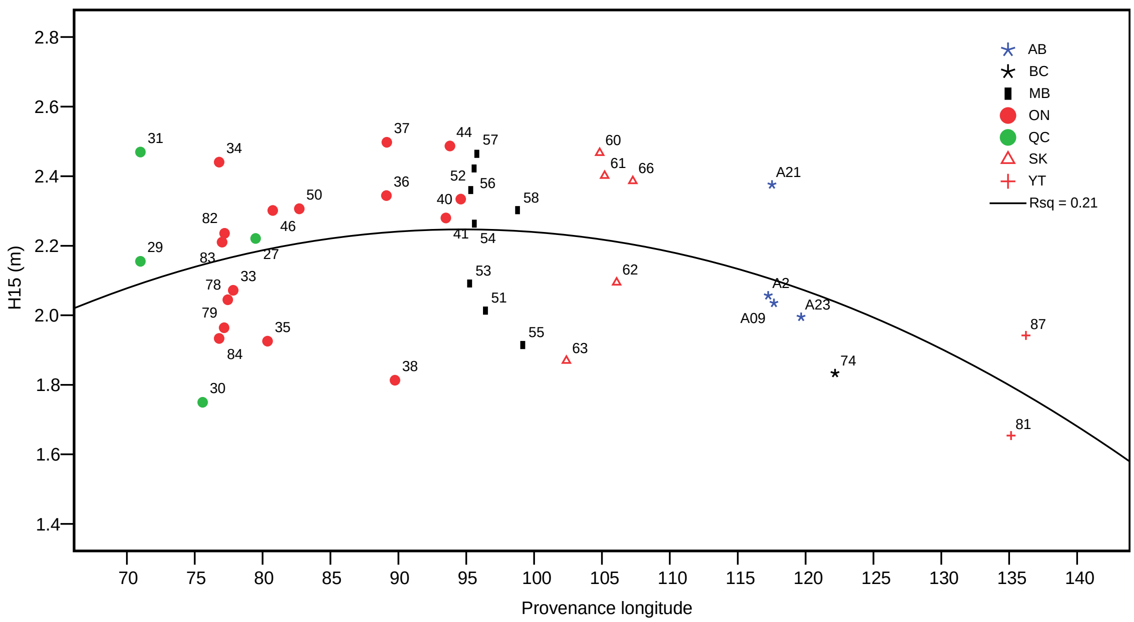


Fig.3 Provenance height growth potential as related to longitude of seed origin in G277A. Data labels are provenance IDs found in Appendix I.

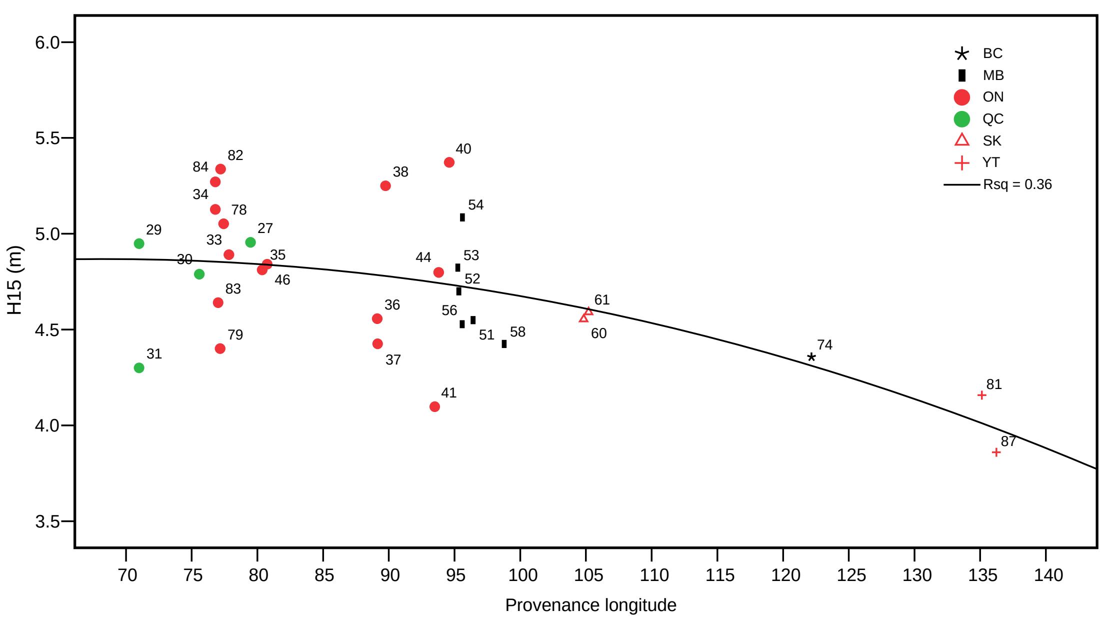


Fig. 4 Provenance height growth potential in relation to longitude of seed origin in G277B. Data labels are provenance IDs found in Appendix I.

Similar relationships were observed for latitude and elevation, and in all cases, they were almost simple linear.

A more recent range-wide provenance trial series involving 90 populations from across western USA and Canada was established in 2005 at two sites in Alberta (Whitecourt and Hay River), 15 sites in British Columbia and one site in Yukon. It includes white spruce, Engelmann spruce (*Picea engelmannii* Parry ex Engelmann), Sitka spruce (*Picea sitchensis* (Bong.) Carr and possibly, hybrids of white spruce with both Engelmann and Sitka spruces. After one growing season, the trial at Hay River (59°08' N, 117°34' W and 370 m) was assessed for post planting survival and climatic-related damages, and the results were reported by Dhir et al. (2007). Dieback incidences and severity were strongly related to winter temperatures at the place of seed origin. The Pearson's correlation for dieback incidence and severity with degree days below 0°C (NDD) were 0.72 and 0.65, respectively. Dieback was the lowest (< 10%) among provenances from regions with cooler winters in Northern British Columbia, Yukon, Northwest Territory and Alberta, and highest (50 – 100%) among provenances from regions with warmer winters in British Columbia and the USA. These drastic differences in provenance susceptibility to winter damages indicates that caution should be exercised when transferring provenances from low to high latitudes to improve growth. High growth potential provenances from low latitudes may not be suitable for harsh climates at high latitudes and elevations.

Table 1. Least square means for Alberta and exotic white spruce provenances in G276 trials at age 15 years at four sites.

ACC#	Location	Site A	Site B	Site C	Site D
0002	Footner Lake, AB	-	4.31 ±0.18	3.74 ± 0.20	-
0004	Walkin Tower, AB	2.03 ± 0.18	-	-	-
0019	Slave Lake, AB	-	-	**4.16 ± 0.20**	-
0021	Peace River, AB	-	5.04 ± 0.25	4.01 ± 0.20	-
0023	Peace River, AB	-	**4.71 ± 0.21**	-	-
0032	Edson, AB	-	-	-	4.99 ± 0.13
0042	Rocky/Clearwater, AB	-	-	-	**5.29 ± 0.13**
0046	Bow/Crow, AB	-	-	-	4.82 ± 0.30
0446	Cypress Hills, AB	1.48 ± 0.18	-	3.85 ± 0.20	5.27 ± 0.15
0784	Steen River,AB	1.79 ± 0.15	3.95 ± 0.19	-	-
1327	Malartic, QE	1.75 ± 0.15	4.88 ± 0.19	-	-
1328	Chicoutimi, QE	1.59 ± 0.16	4.73 ± 0.18	4.23 ± 0.22	4.72 ± 0.17
1352	Indian Bay, MN	2.01 ± 0.14	5.52 ± 0.18	4.85 ± 0.20	5.05 ± 0.14
1378	Chalk River, ON	1.97 ± 0.15	5.28 ± 0.19	3.86 ± 0.20	4.69 ± 0.13
1383	Douglas, ON	1.78 ± 0.15	5.29 ± 0.18	3.92 ± 0.20	5.41 ± 0.13
2409	Whitemud Hills, AB	**1.74 ± 0.14**	**4.34 ± 0.17**	-	-
2416	Slave Creek, AB	1.75 ± 0.14	4.16 ± 0.17	-	-
3078	Marchland, MN	2.13 ± 0.15	4.98 ± 0.18	4.74 ± 0.20	5.22 ± 0.13
3079	White Shell, MN	2.18 ± 0.15	5.15 ± 0.18	3.61 ± 0.20	5.63 ± 0.13
3080	Bissett, MN	2.15 ± 0.14	5.18 ± 0.18	4.02 ± 0.20	5.61 ± 0.13
3081	Manigotagan, MN	2.26 ± 0.15	-	3.95 ± 0.20	5.65 ± 0.13
3083	Bloodvien River, MN	2.02 ± 0.14	4.70 ± 0.18	4.47 ± 0.20	5.55 ± 0.13
3240	Edson, AB	-	-	-	**5.65 ± 0.14**

A –Alberta Pacific Forest Industries site (55°55' N; 112°51' W; 580m); B –Whitecourt Mountain (54°03' N; 115°47' W; 823m)
C – Kinosis Lake (56°18' N; 110°58' W; 495m); D –Diamond Hills (52°37' N; 115°05' W; 990m);

4.2.2 Genetic Studies of Alberta white spruce in Alberta

White spruce is the most important tree species in Alberta accounting for 45.9% of the province's conifer volume and 27.9% of the combined volume of coniferous and deciduous species, respectively (AFLW, 1985). Ecologically, the most variable terrain of white spruce's natural range occurs in Alberta making Alberta the most suitable place for studying genetic variation in this species. A great potential for population variability implies that thorough provenance exploration is needed to determine the extent and pattern of population variability, which is essential for proper matching of seed source regions to planting regions. Provenance testing is also an essential component in zoning the Alberta white spruce breeding and tree improvement program.

Progeny or family testing designed to quantify genetic variation within population and estimate genetic parameters such as heritability and genetic correlation is needed to determine the extent with which tree traits can be changed by selection and breeding. In this section, we discuss in detail, results of ongoing genetic field studies of provenances and progenies of Alberta seed origin.

4.2.2.1 Alberta Provenance Studies: Height

Extensive provenance testing of white spruce in Alberta was initiated in 1975 in what is known as the G103 series of provenance trials. The series contains 46 white spruce provenances from across Alberta with the geographic range of 49°38° – 59°53' N, 110°14' – 119°35' W and 183 – 1600 m in elevation (Appendix II). Subsets of these provenances are planted on 8 active sites, each containing 26 – 30 provenances that include a set of 19 provenances that are common to all sites. These trials were established between 1980 and 1983 and trees in the oldest trials are currently 33 years old. The experimental layout for all trials is a randomized, complete-block design with 9-tree row plots and 2.5 × 2.5 m spacing. Extensive analysis for survival, height and diameter at breast height (DBH) growth were carried out for 15- and 24- year measurements from germination and results were reported by Rweyongeza and Yang (2005) and Rweyongeza et al. (2007).

Using an intraclass correlation from the combined-site analysis of 21 provenances that are planted on at least 6 of the 8 sites, it was found that 10.6% and 6.6% of the total provenance phenotypic variance for 24-year height (H24) and DBH (D24) was due to variation among provenances, respectively (Rweyongeza and Yang 2005; Rweyongeza et al. 2007). Thus, about 89% (H24) and 93% (D24) of the genetic variation in white spruce in Alberta is within populations. The provenance × site interaction was significant ($P < 0.0001$) accounting for 3.8% and 3.1% of the total provenance phenotypic variance for H24 and D24, respectively (Rweyongeza and Yang 2005). In comparison, this genotype × environment (GE) interaction variance was 62.2% (H24) and 74% (D24) of the provenance variance. The Type B provenance correlation between sites for H24 ranged from -0.59 ± 0.24 to 1.0. Likewise, the correlation for D24 ranged from -0.35 ± 0.28 to 1.0 (unpublished data).

In Alberta, elevation is lowest at high latitudes in the north and highest at low latitudes in the southwestern part of the province. Consequently, provenance growth potential declined from central Alberta northward with an increase in latitude and southwestward with an increase in elevation. Thus, the relationship of growth potential with latitude and elevation of seed origin is best described by a parabolic transfer function depending on the location of the test site (Figure 5). Statistics for these transfer functions are summarized in Table 2. No relationship has been observed between growth potential and longitude of seed origin ($R^2 < 0.1$)

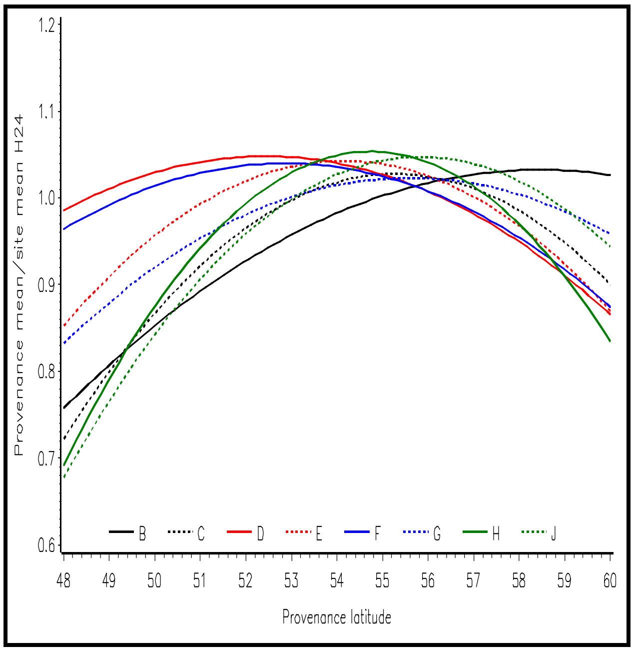
Table 2. Site means, range of provenance means, coefficients of determination and predicted optimum provenance latitude and elevation for 24-year height for eight sites in G103 trials.

Site	Mean and Range	Latitude		Elevation	
		R^2	Optimum	R^2	Optimum
Hay River (B)	4.69 ± 0.11 (3.69 – 5.21)	0.44**	58°22'	0.41**	142
Slave Lake (C)	3.85 ± 0.25 (3.27 – 4.36)	0.38**	55°17'	0.35**	772
Sexsmith (D)	6.58 ± 0.16 (5.52 – 7.10)	0.61***	52°25'	0.52***	1087
Swartz Creek (E)	6.59 ± 0.13 (5.38 – 7.20)	0.47**	54°08'	0.64***	902
Prairie Creek (F)	5.04 ± 0.20 (4.15 – 5.70)	0.36**	52°52'	0.59***	964
Chinchaga (G)	6.31 ± 0.24 (5.40 – 6.78)	0.44**	55°33'	0.52***	779
Calling Lake (H)	5.62 ± 0.15 (4.28 – 6.48)	0.45***	54°46	0.73***	849
Hangingstone (J)	6.50 ± 0.19 (4.46 – 7.15)	0.47***	55°50'	0.60***	737

** -$P < 0.01$; *** -$P < 0.001$

Using multivariate climatic indices, Rweyongeza et al. (2007) suggested that with respect to white spruce growth potential, Alberta could be divided into southern, central and northern regions. The central region refers to the zone between latitude 54° and 57° N, the northern region is the zone north of latitude 57° N and the southern region is the zone south of latitude 54° N. Climatically, the central region is characterized by relatively mild winters, warm summers and high precipitation. The northern region has very cold winters, warm summers and low precipitation leading to high continentality. The southern region is the foothills and Rocky Mountainous region characterized by mild winters and cool summers due to oceanic influence, high precipitation, low growing degree days (Alberta Environment 2005) and a short frost-free period (AARD 2005).

The detailed discussion of the relationship between H24 and individual climatic variables, which illustrates the degree of adaptation of individual provenances to climate in Alberta is provided in Rweyongeza et al. (2007) and Rweyongeza and Yang (2005). It suffices here to mention that in terms of growth potential, the northern region has a pronounced latitudinal cline where growth potential declines northward with an increase in latitude partly as a response to cold temperatures, continentality and most likely photoperiod; the southern region has an elevation cline where growth potential declines with an increase in elevation in response to a shorter and cooler growing season; the central region has only a weak latitudinal cline where growth potential declines northward at a much lower rate than the northern region.



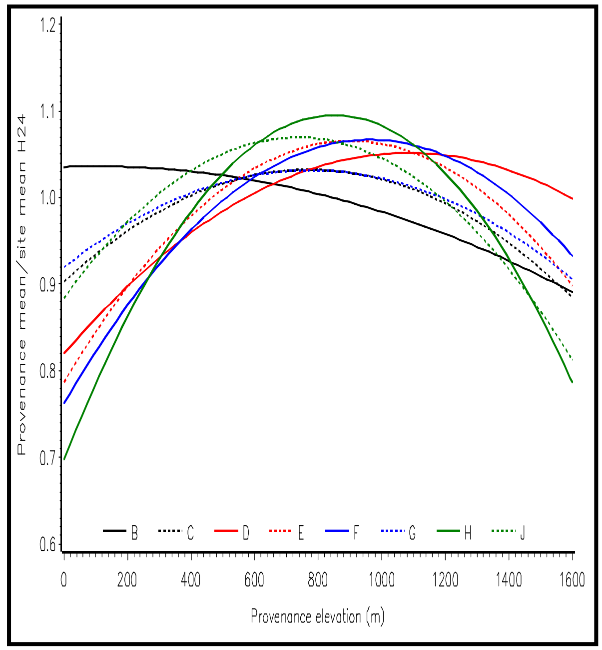


Fig. 5 Individual site latitudinal and elevation transfer functions for 24-year height.

Table 3 shows Pearson's correlation coefficients for H24 with latitude, longitude and elevation at the place of seed origin to illustrate clinal variation within the three geographic/climatic regions as expressed on individual and across sites. High and significant positive correlations between H24 and elevation in the northern region simply indicate a reversed latitudinal trend where growth potential increases with a decrease in latitude of seed origin. Latitudinal and elevation clines within regions are further illustrated in Figure 6. Because of large differences in height growth among sites, H24 has been standardized by dividing the provenance mean by the site mean so that data from all sites can be plotted together (see also Figure 5).

Table 2 shows that for most sites, provenances of highest growth potential are expected to originate from between 54°N and 56°N, and elevation of 700 to 1100 m. As described earlier, this optimal environment is predominantly within the central region. Higher latitude provenances are the most favourable seed sources in the northern region (e.g., site B). Although site F is located at 1220 m, its optimum provenances are predicted to originate from below 1000 m (Table 2). This suggests that for high elevation regions (southern region), provenances from a slightly lower elevation could be used in reforestation. However, it should be noted that, although the regressions support the three-region grouping of Alberta white spruce in terms of growth potential, it was also observed that for all sites, the local provenances were among the best for H24. Thus, choice of populations for genetic improvement and reforestation should seek to maximize adaptation and gain by using seeds closest to the reforestation region.

Table 3. Pearson's correlation coefficients for 24-year family mean height with latitude, longitude and elevation of seed origin within three white spruce geographic regions in Alberta.

SITE	NORTHERN				CENTRAL				SOUTHERN			
	N	LAT	LON	ELEV	N	LAT	LON	ELEV	N	LAT	LON	ELEV
Hay River (B)	9	-0.06	-0.11	0.13	12	-0.05	-0.12	-0.02	5	0.35	0.00	-0.11
Slave Lake (C)	6	-0.79	0.60	0.85*	17	-0.03	-0.68*	-0.65**	5	0.35	-0.07	-0.58
Sexsmith (D)	7	-0.79*	0.30	0.63	12	-0.48	0.18	0.09	6	-0.23	-0.12	-0.29
Swartz Creek (E)	7	-0.77*	0.55	0.86*	10	-0.59	-0.03	-0.18	8	0.22	-0.30	-0.85**
Prairie Creek (F)	7	-0.61	0.43	0.51	8	-0.55	-0.10	0.33	10	0.11	-0.25	-0.72*
Chinchaga (G)	7	-0.83*	0.39	0.83*	13	0.06	0.02	0.06	6	0.32	-0.14	-0.58
Calling Lake (H)	7	-0.65	0.58	0.81*	15	-0.30	-0.56*	-0.39	6	0.17	-0.16	-0.91*
Hangingstone (J)	10	-0.72*	0.58	-0.77**	10	-0.34	-0.11	0.38	6	0.33	-0.09	-0.49
Pooled data+	54	-0.61***	0.37**	0.60***	64	0.20	-0.17	-0.06	52	0.11	-0.17	-0.53***
Across Sites++	7	-0.84*	0.49	0.83*	8	-0.50	-0.40	-0.14	6	0.10	-0.36	-0.88*

* -*P ≤ 0.05*; ** -*P ≤ 0.01*; LAT, LON and ELEV –latitude, longitude and elevation of seed origin, respectively; Central (54° – 57°N); Northern (> 57°N); Southern (< 54°N); + -Correlations when data are pooled (not averaged) across sites for the 21 provenances planted on at least 6 of the 8 sites (see also Figure 6); ++ -Correlations when data are pooled (not averaged) across sites for the 21 provenances planted

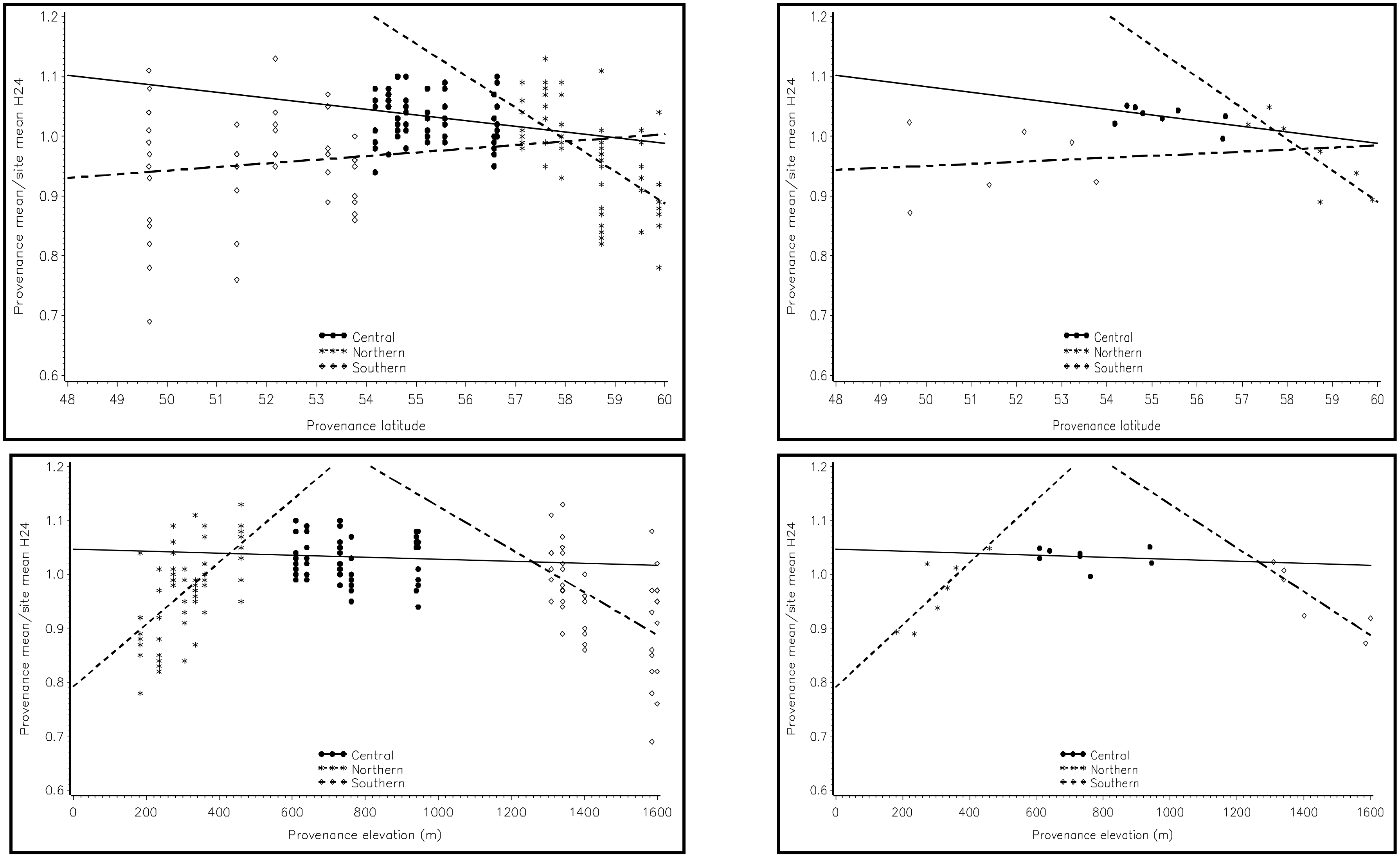


Fig. 6 Geographic clines within regions.
With data (left) and data averaged across sites (right) for 21 provenances.

4.2.3 White Spruce Progeny Testing in Alberta

Progeny or family testing designed to provide estimates of genetic variation within populations and various genetic parameters in support of the white spruce breeding program in Alberta began in 1986. Many progeny trials have been established across the province and are linked to specific breeding regions. These trials contain between 50 and 150 half-sib families from open-pollinated seed collections and are replicated on 2 to 4 test sites. Periodic assessments for survival, growth, diseases and insect damages are performed in these trials to estimate heritability, genetic correlations between traits, genotype × environment interaction, and how these genetic parameters vary with tree age. Genetic parameters from these trials are used to estimate breeding values and expected genetic gain, which are then used to rogue seed orchards associated with those trials. Table 4 briefly describes the oldest progeny trials and provides genetic parameters for earlier measurements. Some of these trials (e.g., G135 and G156) have since been reassessed and genetic parameters will be continuously updated as trees grow older.

Table 4. Summary of white spruce genetic studies in Alberta.

Study or Reference	Materials and Field Testing	Results - Genetic Parameters
G132 series half-sib family tests for Regions D and D1 (ATISC unpublished data)	150 half-sib families; 4 test sites; Central mixedwood; 10 and 15-year results.	1. Heritabilities for 10-year height(combined sites): $h_i^2 = 0.19$; $h_f^2 = 0.73$ 2. Heritabilities for 15-year height(combined sites, 3 sites data): $h_i^2 = 0.24$; $h_f^2 = 0.73$ 3. Site by family interaction for height significant at 10-years representing 1% of total variation; not significant at 15-years (Carson Lake site, in Region D, not included in analysis) 4. White pine weevil (WPW) incidence, family heritability at 10 and 15-years = 0.48 and 0.62 respectively (based on two sites with 32.7% and 27.1% incidence at 10-years and 14.4% and 21.6% incidence at 15-years; family mean correlations between sites = 0.31 and 0.45 for 10 and 15-year assessments, respectively 5. Genetic and phenotypic correlations 10yr/15 yr height 0.98 and 0.94, respectively 6. Range of Type B genetic correlations among site pairs = 0.42-0.71 (10-yr), 0.46-0.79 (15-yr) and family mean correlations = 0.34-0.54 (10-yr) and, 0.41-0.66 (15-yr)
G135 half-sib family tests for Regions G1/G2 (ATISC reports TIC 96-11 and 1996 report to MDFP Research Trust Fund)	69 - 71 families; 2 test sites (G135 A and G135B); Peace River region (Boreal mixedwood); 11-year results 69 families; 1 test site (G135A); 18-Yr results	1. Heritabilities for 11-year height (individual sites): $h_i^2 = 0.12 – 0.23$; $h_f^2 = 0.28 – 0.42$ (combined site analysis has not been carried out) 2. Heritabilities for 18-year height: $h_i^2 = 0.16$; $h_f^2 = 0.30$. Heritabilities for 18-year Dbh: $h_i^2 =0.16$; $h_f^2 = 0.31$; genetic and phenotypic correlations between 18-year height and Dbh were 0.91 and 0.96 respectively. Genetic and phenotypic correlations between 11 and 18-year height were 0.88 and 0.89, respectively (one site data at G135A site) 3. 11-yr height/tree vigor score correlations: $r_p = 0.76$; $r_g = 0.68$ (one site data) 4. WPW incidence at two sites at 11-year assessment varied from 2.0% to 8.6% 5. WPW incidence at 18-year age on G135A site was 5.7 percent and family effects were not significant

G156 series half-sib family field tests for Region E (ATISC report ATISC 04-22)	53 families; 3 test sites; NE Boreal region (Boreal mixedwood); 11-year results	1. Heritability for 11-year height (combined sites): h_i^2=0.18; h_f^2=0.63 2. Site by family interaction for height not significant (0% of total variance) at 11-years age 3. Range of Type B genetic correlations among site pairs for 11-yr height = 0.30-0.70; family mean correlations for 11-yr height = 0.41-0.67 4. Type B family mean correlations between sites for 11-year survival were not significant (r = -0.05 to 0.18). Family mean correlations between 11-yr height and survival were also not significant (r = -0.6 to 0.14) 5. WPW incidence at age 11 at three sites was 1.2% (G156A), 1.4%(G156B) , and 30.1% (G156C). Family mean correlation between one site pair (G156B and G156C) was significant (r = 0.37) 6. Heritability for WPW for the site with highest WPW: h_i^2=0.19, h_f^2=0.60 7. Correlation between 11-year height and mature parent tree wood density was not significant (r =-.12, R^2 = 0.014)
G133 provenance-family tests for northern Alberta (ATISC report 05-17)	125 families from 23 stands represented by 4-10 families per stand; 3 test sites located in NW Boreal region; materials were collected from NE and NW Boreal regions; 11-12, and 18-year results	1. Heritabilities for 12-year height (combined sites): h_i^2 = 0.09; h_f^2 = 0.36; h^2_w = 0.07 2. Heritabilities for 18-year height (combined sites): h_i^2 = 0.08; h_f^2 = 0.35; h^2_w = 0.06 3. Heritabilities for 18-year dbh (combined sites): h_i^2 = 0.08; h_f^2 = 0.36 4. Coefficient of additive genetic variation = 9.57% and 9.62% , respectively for 12-year and 18 year height 5. Stand variation component was significant and amounted to 70.2% and 96.6% of family- within-stands variance component for 12-yr and 18-yr height, respectively 6. Site by families-in-stands interaction was not significant for 12-yr and 18-yr height and dbh 7. WPW incidence at age 18 at three sites was 28.1% (G133A), 4.0% (G133B), and 14.1% (G133C). Family mean correlations among site pairs were significant and varied from 0.34 to 0.42 8. Heritability for WPW at 18-yr for the site with highest WPW: h_i^2=0.18, h_f^2=0.45
G157 half-sib family field test for Region H (ATISC unpublished data)	50 families; 3 test sites; NW Boreal region (Boreal mixedwood); 11-year results	1. Heritability for 11-year height (individual sites): h_i^2=0.07 to 0.15; h_f^2=0.23 to 0.38 2. Heritability for 11-year height (combined sites): h_i^2=0.03; h_f^2=0.21 3. Site by family interaction for height was significant (1.5% of total variance) at 11-years age and was 250% of the family variance component 4. Type B family mean correlations between site pairs for 11-year height were not significant (r = 0.03 to 0.19) 5. WPW incidence at age 11 at three sites was 27.8% (G157A), 8.1% (G157B), and 10.4% (G157C).

h_i^2 = individual tree heritability; h_f^2 = family heritability; h^2_w = within family heritability; r_g = genetic correlation; r_p = phenotypic correlation

4.2.4 White Pine Weevil

White pine weevil (*Pissodes strobi* [Peck]) is an important pest of white spruce throughout the species range and is known to cause extensive damage in young plantations. In this section, we review white pine weevil (WPW) attacks reported elsewhere in Canada and provide preliminary observations and inferences on weevil damages in field trials within Alberta. For simplicity, WPW damages in Canada-wide and Alberta-wide populations are discussed in the same section. Kiss and Yanchuk (1991) studied incidence of WPW attacks in three interior spruce open-pollinated progeny tests in north central British Columbia (BC) and found that the damage in individual plantings varied from 9% to 63%. Correlations of family means among site pairs were high (r = 0.63 - 0.71). Family mean heritability for WPW across plantings was 0.77, whereas individual tree heritability was 0.18. The correlation of family mean height and diameter with weevil damage was -0.51 and -0.44, respectively, indicating that weevil-damaged trees tended to have low height measurements and low vigour.

In the Canada-wide provenance trial at Calling Lake (G103RW), the cumulative WPW incidences based on assessments made at ages 15, 21 and 24 years were the highest among provenances from British Columbia and Yukon (Figure 7). There were also high incidences of WPW for some of the provenances from Nova Scotia, Quebec and Ontario, although most of provenances from eastern Canada sustained low weevil damages. WPW attacks were prevalent in years before age 24 and appear to have subsided thereafter. Between age 24 and 27, new attacks were minor (mean 0.7%, range 0 – 13%) and only occurred in 4 of the 43 provenances.

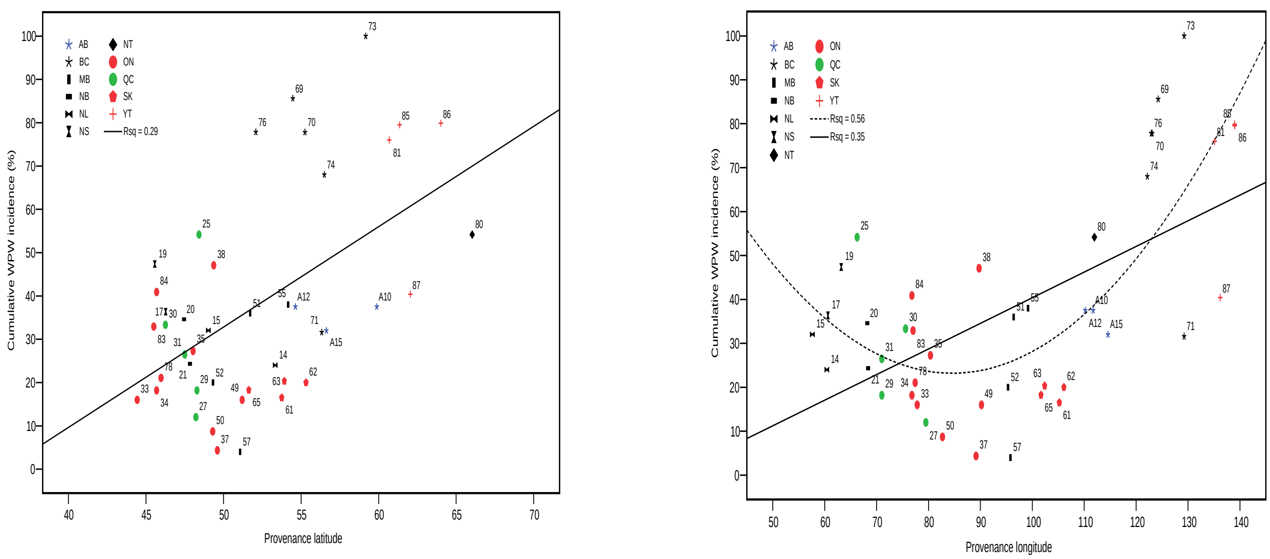


Fig. 7 Cumulative white pine weevil infestation in relation to latitude and longitude of seed origin in the G103RW Canada- wide provenance trial based on assessments made at ages 15, 21 and 24 years.

Note: Data labels are provenance IDs shown in Appendix I

In the G103 series of provenance trials in Alberta, incidences of WPW have been scored at different tree ages. Preliminary examination of the data indicated that the age at which trees were most attacked by WPW differed among sites. It also showed that the percentage of trees attacked at any site differed considerably among tree ages. Thus, there is a need for developing an effective method of analyzing WPW incidences cumulatively because not all trees may have been exposed to the weevil at the same time. In addition, there is a need for a method that accounts for multiple periodic infestations on the same tree to avoid overestimation of cumulative WPW incidences. In the meantime, a preliminary analysis of cumulative weevil incidence in the G103 trials has been conducted using weevil data scored at age 15, 21, 24 and 27 years. Because no method had been established for tracking WPW incidences when these trials reached age 15 years, 15-year weevil scores for all sites were derived from the tree condition codes. In this case, any tree with an ATISC tree condition code "I" (simply defined as insect/disease attack considered serious enough to depress tree growth) was considered a WPW incidence (**Note:** based on experience of field assessment personnel). The same method was used to derive weevil incidences for only a few other ages for some sites where WPW attacks were not specifically recorded. Cumulative WPW incidence (CW) was then derived as a sum of percentage incidences for 15 (W15), 21 (W21), 24 (W24) and 27 (W27) ages, that is, $CW = W15 + W21 + W24 + W27$.

It should be noted that CW derived this way assumes that a tree scored for a positive weevil attack at one age will not be rescored for the same attack at a different age or on the new leader. Because the current CW likely contained data where some trees have been scored more that once, actual percentage CW incidences are likely to be lower than those reported here. Nevertheless, because all provenances have been treated the same way, the current CW is considered adequate for determining provenance differences in susceptibility to WPW.

Table 5 contains site means, range of least square provenance means, and statistical tests for the provenance effect for CW. Also included in Table 5 are coefficients of determination (R^2) for the regression of CW on latitude, longitude and elevation of seed origin, and the Pearson's correlation between 24-year height and CW. Except for Hay River (B), there were significant ($P < 0.05$) provenance differences for CW at all sites and across sites. These provenance differences were associated mainly with elevation of seed origin for all sites, except site F. Figure 8 shows that provenances from high elevations and those from high latitudes had relatively higher weevil attacks than provenances from intermediate latitudes and elevations.

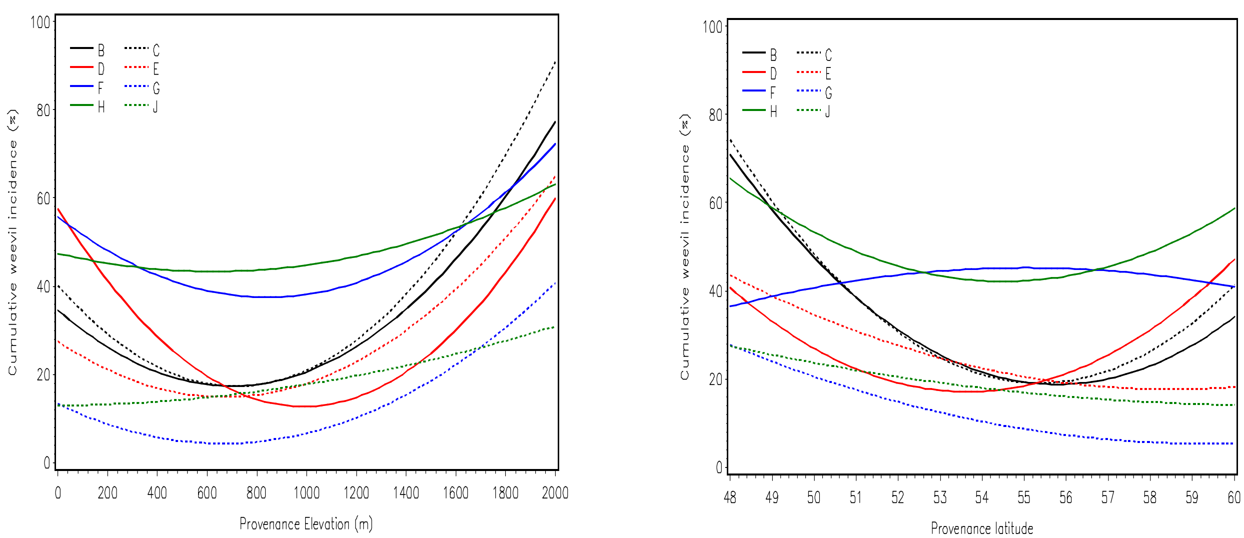


Fig. 8 White pine weevil cumulative infestation in relation to elevation and latitude of seed origin in the Alberta provenance trial series G103 at eight sites.

Note: Regressions and ANOVA (Table 5) included 2 Engelmann spruce provenances. Letters indicate test sites; each site contains 26 to 30 provenances.

Table 5 also shows that height growth was negatively correlated with weevil damage. This negative correlation could be interpreted in two different ways. (i) on the positive and genetic side, it would mean that provenances of high growth (vigour) potential are more likely to resist insect attack than those of low vigour. This is likely in the present case, because provenances from central Alberta, which are known to have high growth potential, had relatively lower CW than provenances from other regions. Thus, selection for growth would be expected to reduce WPW incidences and intensity in tree plantations. (ii) on the negative and non-genetic side, it could mean that weevil-damaged trees, and thus provenances, are more likely to be reported as inferior in term of growth potential than weevil resistant ones merely because of physical damage. This is also likely because the loss of apical dominance and terminal growth leads to multiple leaders/forking that redistribute primary growth to many lateral shoots. It also causes measurement errors where trees are re-measured at different ages during which different leaders may be measured. Thus, in trials with substantial WPW infestation, adjustment for weevil damage may be needed when analyzing height growth.

Incidences of WPW have also been assessed and genetically analyzed in Alberta white spruce family trials (G133, G132, G135 and G156) and results are summarized in Table 4. It shows that family mean heritability was high (h_f^2 = 0.45 – 0.62), whereas individual tree heritability was relatively low (h_i^2 = 0.18 and 19) similar to that observed by Kiss and Yanchuk (1991). In the G133 progeny trials, WPW incidence at age 18 years showed a west ward increase in susceptibility with highest infestation occurring among families from between 117^o and 120^o. However, this longitudinal trend does not appear to extend east of 117^o W (Figure 9).

Table 5. Cumulative white pine weevil attack and its relationship with seed origin and height growth potential in the Alberta wide white spruce provenance trials (G103).

Site	Mean and Range	F-Value	P > F	LAT[a]	ELEV[a]	LON[a]	H24[b]
Hay River (B)	24.4 ± 2.2 (3.8 – 55.9)	1.38	0.1397	0.29*	0.33**	0.05	-0.57**
Slave Lake (C)	23.4 ± 2.4 (0.0 – 55.0)	1.78	0.0204	0.26*	0.37**	0.14	-0.47*
Sexsmith (D)	25.5 ± 2.0 (4.7 – 62.8)	2.79	0.0001	0.26*	0.42**	0.01	-0.72***
Swartz Creek (E)	22.8 ± 1.8 (8.9 – 69.4)	2.84	0.0001	0.16	0.59***	0.01	-0.53**
Prairie Creek (F)	43.7 ± 3.4 (25.4 –81.4)	2.21	0.0026	0.01	0.26*	0.08	-0.38
Chinchaga (G)	10.4 ± 1.4 (0.0 – 44.7)	2.28	0.0015	0.15	0.51***	0.02	-0.27
Calling Lake (H)	47.7 ± 2.3 (15.6 – 76.5)	1.95	0.0070	0.08	0.08	0.26*	-0.52**
Hangingstone (J)	17.6 ± 1.4 (2.5 – 46.2)	1.78	0.0204	0.10	0.22*	0.17	-0.30
Across sites+	27.4 ± 1.7 (14.9 – 46.8)	5.31	0.0001	0.12	0.33*	0.07	-0.60***

[+] Involves 21 provenances planted on at least 6 of the 8 sites; [a] –coefficient of determination (R^2) for cumulative weevil attack;
b –Pearson's correlation between 24-year height and cumulative weevil attack

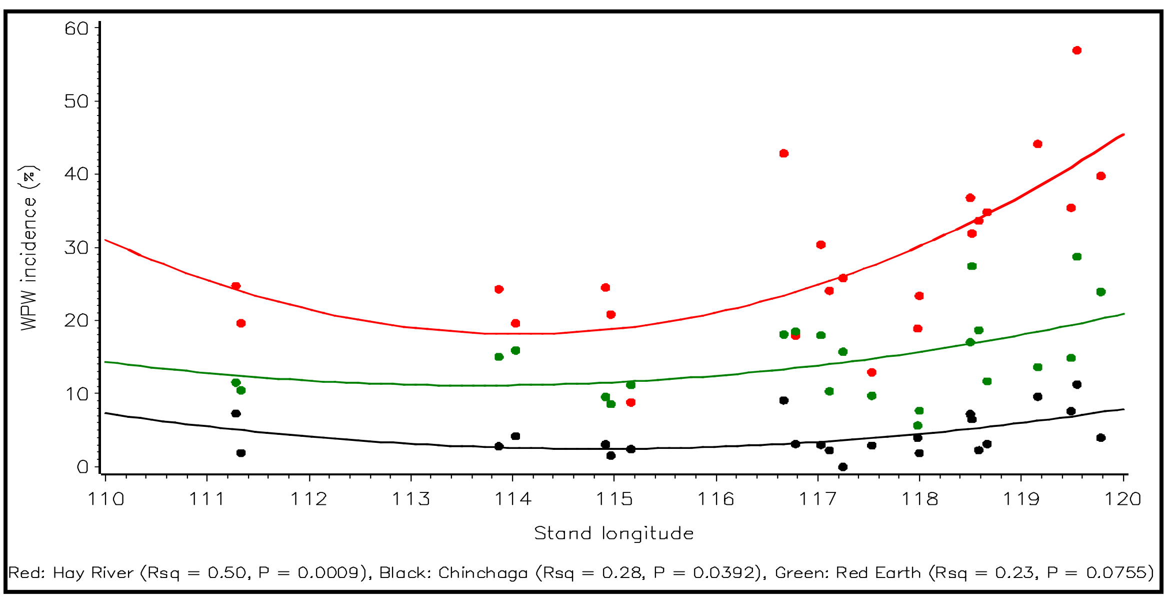


Fig. 9 Relationship of white pine weevil incidence to longitude of seed origin in northern areas provenance-family trials.

4.2.5 White Spruce Base Population for G2 Breeding Region

The Alberta white spruce genetic improvement program is divided into ten breeding regions illustrated in Figure 1. In this section, we review the genetic information at a provenance level to evaluate the suitability of the existing base population for the G2 breeding region. The term adaptation in this section is used restrictively to imply the ability of a provenance or family to attain above average height growth in a specified environment.

Among the G103 series, site G trial located at the Chinchaga River experimental area (57°50 N; 118°12' W and 470 m) is within the G2 breeding region, although its elevation is slightly below the operable area. On the contrary, site D trial located near Sexsmith (55°31' N; 118°30' W and 805 m) is slightly outside G2 in terms of latitudes but its elevation is within G2 operable limits. In addition, its winter and summer temperatures measured by NDD and GDD, respectively, are similar to that of the southern portion of G2 (see Rweyongeza et al. 2007). Individual site analysis for tree height at age 24 (H24) showed that for site G, local provenances and those from 2° to 3° south of the site had the highest H24. At site D, provenances with the highest H24 were largely those from higher elevations south of the test site, although some of the local provenances also did well. While the estimated optimum elevation for site D is only slightly outside the operable elevation for the G2 breeding region, the optimum latitude is too far removed from the G2 north-south operable area (Table 2). This is undoubtedly due to unexpected better performance of some of the Upper Foothills and Subalpine provenances at this site.

Although neither site D nor G is centrally located in the G2 breeding region, they provide an opportunity for evaluating the suitability of the parent trees selected for genetic improvement in the G2 breeding region. Figures 10 and 11 show the regression of H24 on provenance latitude and elevation when data for the two sites were pooled (not averaged) so that performance of individual provenances could be compared at the two sites. Because average growth differs at the two sites, H24 has been standardized by dividing the provenance mean to the site mean. The R^2 is 0.32 ($P < 0.0001$) and 0.34 ($P < 0.0001$) for latitude and elevation, respectively, which is lower than those of individual sites (Table 2), because the pattern of provenance variability differs substantially between sites. In both Figures 10 and 11, the two vertical solid lines mark the boundaries of the G2 breeding region. The dashed horizontal line indicates the overall mean height, that is, provenances above this line had above average H24 at a given site and vice versa.

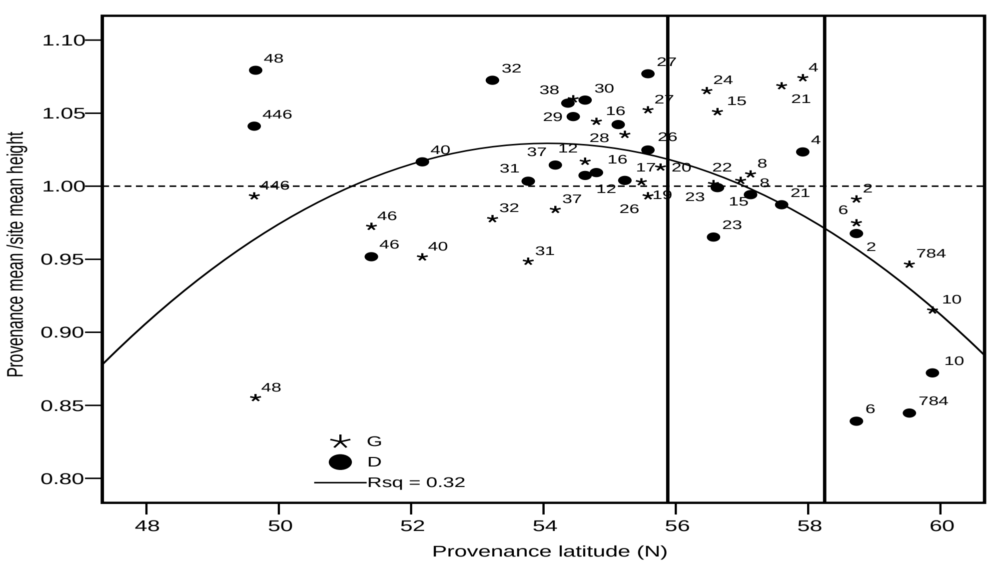


Fig. 10 Relationship between H24 and provenance latitude at sites D and G.
Data labels are provenance IDs found in Appendix II.

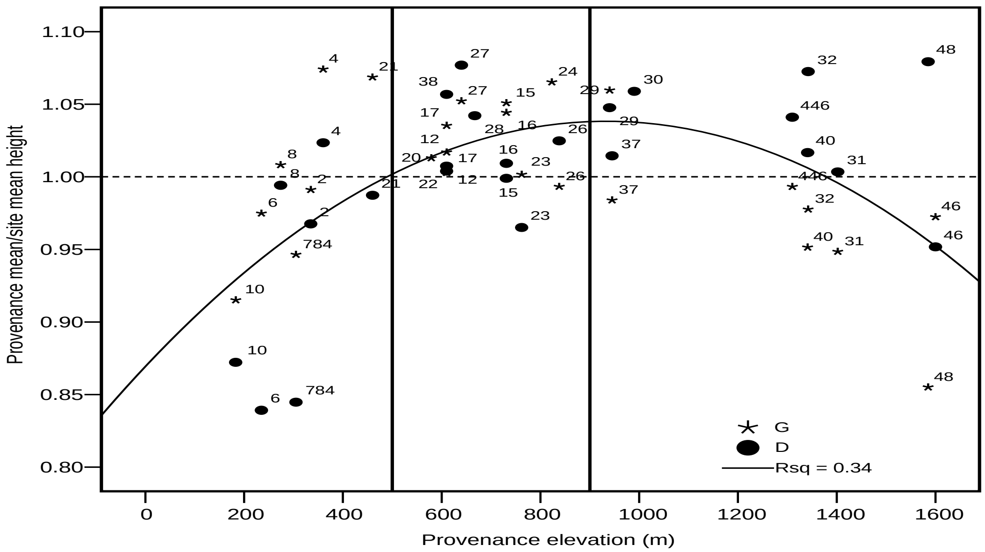


Fig. 11 Relationship between H24 and provenance elevation at sites D and G.
Data labels are provenance IDs found in Appendix II.

The purpose of these plots is to identify provenances that grew well on both sites and that are within or close to the boundaries of G2. Because G2 is treated as a region, not a mosaic of sites that have to be reforested individually, the suitable provenances for this region are those with above average H24 at both test sites and that originate from within the G2 breeding region boundaries. Provenances that had above average growth at both sites but originate from outside the breeding region boundaries are considered appropriate for G2 only if they are within a "practical" latitudinal or elevation distance from G2. Such provenances indicate a potential for introducing superior seed sources from outside the breeding region with a minimum risk of maladaptation for traits other than growth. They could also indicate the potential for altering the current G2 boundaries to incorporate surrounding areas.

Figure 10 shows that provenances from north of the G2 breeding region grew poorly at both sites and are considered undesirable for G2. While high elevation provenances further south of G2 (e.g., 48, 40, 32, 31) did well at site D, they grew poorly at site G. These too are considered undesirable for G2 and are the most likely cause of the observed GE interaction between the two sites. The Type B provenance correlation between sites D and G was 0.04 ± 0.31 for H24 and 0.30 ± 0.31 for D24 (unpublished data), which indicates that there was virtually no correspondence in provenance ranking between the two sites. However, this lack of correlation is due to better growth of some of the Upper Foothills and Subalpine provenances at site D, and their poor growth elsewhere. It can be shown that if only two provenances (48 and 32), which exemplify this inconsistent performance between sites D and G the most were dropped from the analysis, the Type B correlation between the two sites for H24 would be 0.83 ± 0.24. This suggests that if only provenances that are relevant for G2 were considered, the correlation between sites D and G would be nearly perfect.

Lack of correlation of site D with sites located outside the Upper Foothills region (B, C, G, H and J) was also evident. The H24 Type B provenance correlation of site D with these sites ranged from -0.59 ± 0.24 (D and B) to 0.59 ± 0.21 (D and H). The only high correlations involving site D were 0.77 ± 0.17 (D and E) and 0.85 ± 0.16 (D and F). Site E (990 m) and F (1220 m) are located at relatively higher elevations than other sites where high elevation provenances are expected to do well as the test site and provenance environment becomes increasingly similar. Thus, provenance ranking at site D is typical of what would be expected for a site located at a much higher elevation.

Figure 10 shows that provenances such as 4, 27, 16, 17, 29 and those originating from similar areas that were tested on only one of the sites are the best material for Region G2. These provenances indicate that adapted material for the G2 breeding region could originate anywhere between latitude 54^o and 58^{o}N by limiting the elevation to between 400 m and 1000 m (Figure 11).

Figure 10 shows that area-wise, most of the operable area of the G2 breeding region lies between 600 m and 850 m, whereas most parent trees in the breeding program originated from between 700 m and 900 m. In terms of latitudes, Appendix II shows that parent trees for G2 base population originated from 54^{o}27' – 58^{o}20'N and 400 – 999 m. Only 4 and 2 of the 99 selected parent trees originated south of 55^{o}N and north of 58^{o}N, respectively. This shows that selection of parents for the base population has been conservatively limited to the breeding region boundaries, thus capturing the most adapted materials for the region. The potential for introducing into G2 superior parents from as far south as 54^{o}N exists when the planting objective is to maximize growth. However, such a need should be balanced with the need to maintain adaptation for climatic tolerance, especially when such materials are to be planted at the northern edge of the breeding region. The G2 breeding region overlaps between the central and northern region with much of the operable area falling into the central region. Because a weak latitudinal cline where growth potential decreases northward exists in this region, the predominant use of parent trees from the southern portion of G2 assures that productivity is not compromised when deploying orchard seeds over an entire region.

4.2.6 Provenance-Progeny Testing in Region G2

The white spruce genetic testing program has largely been involved with provenance trials without family structure or family trials without a provenance structure. Consequently, the provenance vs. family level genetic variability, and provenance × site vs. family × site interaction could not be measured in the same study. The G133 series is the oldest combined provenance-progeny trial with 125 families sampled from different stands between 55^{o}37' and 58^{o}37' N, 11^{o}17' and 119^{o}47' W, and 305 and 884 m in elevation. In terms of latitudes and elevations, most of the stands and families originated from within the operational geographic limits of the G2 breeding region. The trial is replicated on three tests sites of which two, namely Chinchaga (57^{o}49'N; 118^{o}00' W; 500 m) and Red Earth (56^{o}34' N; 115^{o}19' W; 518 m) are of practical interest for the G2 breeding region. The Hay River site is located further north (59^{o}08' N; 117^{o}34' W; 370 m), which in terms of latitude and elevation falls outside the zone of interest for the G2 breeding region (refer section 4.2.4).

Variation for survival and tree damages, and the partitioning of the variance into stand, family-within stand and genotype × environment interaction for height (H18) and DBH (D18) have been undertaken for 18-year measurements from germination and results were reported by Dhir et al. (2005). Only variation for growth is briefly restated here. The stand effect for H18 accounted for 2.6% and 1.2% of the total variance at Chinchaga (site B) and Red Earth (site C), respectively. The family-within stand effect accounted for approximately 0% of the total variance. However, it should be noted that these relatively negligible proportions of the genetic variance were likely due to high within-site heterogeneity as revealed by an excessive family-within stand × replication interaction (experimental error) effect, which accounted for 33.1% and 50.8% of the total variance at site B and C, respectively. Similar variance estimates were observed for D18. Neither significant stand × site nor family-within stand × site interaction was observed for H18 or D18. Spatial analysis will be undertaken to reduce the experimental error and obtain better estimates for genetic variances. In the meantime, Figure 12 shows that the stand effect for H18 was significant ($P = 0.0033$) only at the Hay River site, which is in Breeding Region H. At this site, trees from stands further south (elevation > 700 m) had lower growth potential than those from the northern region and surrounding areas (elevation < 700 m). This pattern of genetic variation shows that in climatically marginal environments found at high latitudes and high elevations, provenances closest to the site are more favoured in terms of growth and survival than provenances from distant areas. This pattern of variation was also evident in the G103 white spruce series where local provenances grew better than others at Hay River and Prairie Creek sites, despite their poor growth elsewhere (Rweyongeza and Yang 2005). Lack of significant elevation effect at Chinchaga and Red Earth suggests that elevation differences within the G2 latitudinal band are minor and will not practically affect selection of parents and deployment of seeds, provided that the deployment elevation limits of the breeding zone are adhered to. This conclusion is different than much other evidence in white spruce and may be attributable to the interaction of elevational and latitudinal clines in northern Alberta. Breeding Region G2 progeny tests established in 2002 are more specific to the breeding region and contain provenance and progeny test materials which will provide additional data to examine elevation and latitude effects in more detail.

There are other white spruce progeny trials located in the G2 breeding region designed to determine genetic variation in survival, growth and resistance to pests and diseases for families sampled largely from within the breeding region. Families from this breeding region are also being tested outside the region as part of ATISC genetic trial series. Genetic parameters from early assessment of these and other white spruce trials in the province are summarized in Table 4.

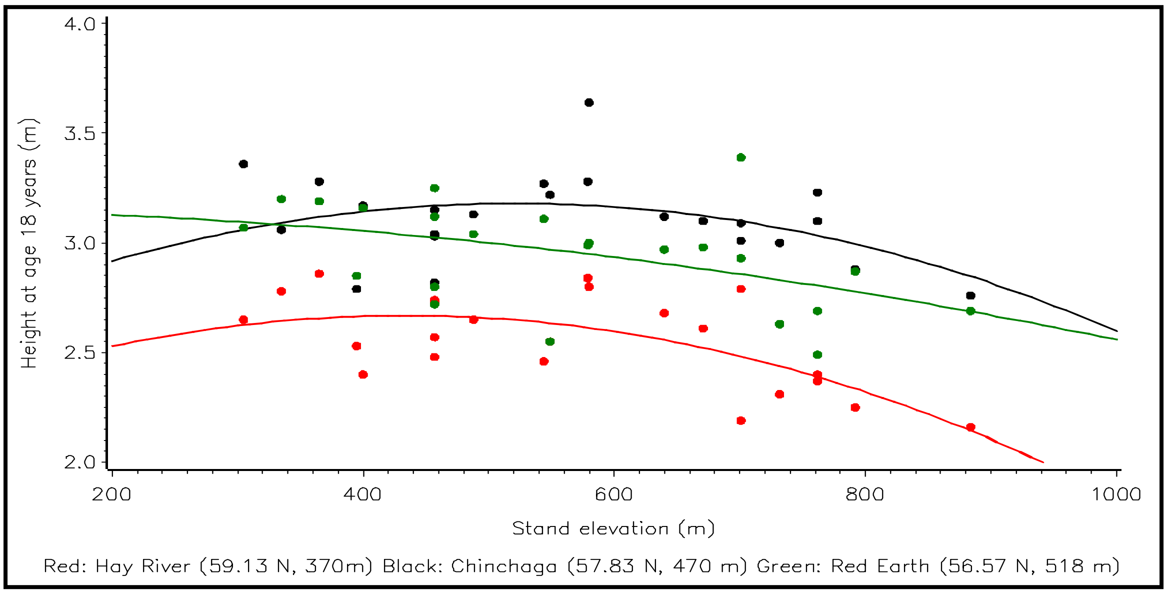


Fig. 12 Relationship between 18-year height with elevation of seed origin in G133 northern areas provenance-family trials.

5.0 PROJECT OBJECTIVES

The project is required to fulfill genetically improved seed needs for reforestation of the appropriate operable areas of the G2 breeding region for the project partners. In addition, the seed may be used for conservation and scientific needs. Deployment zones and strata for reforestation are described in the next section of the report. The total annual planting program using improved white spruce seed for the G2 breeding region is estimated to be 2 million trees per year. The assumption of rotation age for G2 improved stock deployment is 110 years.

The objectives of the tree improvement project are as follows:

- Produce regionally adapted high quality seed for reforestation planting, conservation and scientific needs in Region G2. The seed must meet or exceed genetic adaptation and diversity requirements specified in the STIA for Green Area Deployment in Alberta. The seed, where appropriate, may also be used for afforestation, reclamation of denuded lands, horticulture and woodlot uses.
- Obtain modest genetic improvement for growth and yield and climatic and pest hardiness (particularly WPW) while maintaining baseline wood quality characteristics of the wild population i.e. wood density must not decline with selection and breeding for growth traits.

- Conserve regional wildland resources of white spruce through *in situ* and *ex situ* conservation in accordance with the provincial Gene Conservation Plan for Native Trees of Alberta.
- Carry out and support a limited amount of applied research, genetic stock development and monitoring in support of essential tree improvement activities in the region.

The project described here, has a planned duration of 30 years (1995 - 2025) and is limited to first generation selection and breeding; this adequately fulfills the forest management plan objectives of the project cooperators. MDFP and TIHL are interested in deployment of genetically improved stock to enhance forest productivity and sustainability. ATISC is interested in conservation of wildland genetic resources, strategic seed supply for future needs, genetic stock development for forest improvement and knowledge creation for management of genetic resources in the present and changing climates.

Genetic gain for tree height from the deployment of the improved first generation seed is expected to be about 5% after genetic roguing of the seed orchard is completed. This includes an initial gain from phenotypic mass selection of parent trees. Due to the young age of the G2 progeny tests (7-years), this gain estimate is based on calculations of genetic gain for the rogued Region D1 white spruce seed orchard (File Report ATISC 06-14). Additional genetic gains may be derived through advanced breeding, which is not being considered or proposed at present.

6.0 BREEDING REGION AND DEPLOYMENT ZONE

As discussed in earlier sections, the original Region G white spruce tree improvement project delineated in 1977 was split into a southern G1 and northern G2 section based on changes in forest tenure and cooperating partners. Breeding Region G2 as currently delineated is depicted in Figure 13.

The general parameters and limits considered in defining breeding region boundaries for the G2 project were as follows:

- Latitudinal range not to exceed two and one-half degrees.
- Elevational range from the lower to upper boundary limit not to exceed 500 m.
- Boundaries for the region kept within a homogenous bioclimatic area.
- Integrity of the Forest Management Unit (FMU) and Forest Management Agreement (FMA) boundaries maintained.

6.1 Location and Area

Breeding Region G2 lies between 55°53' and 58°15' N latitude and 117°00' and 120°00' W longitude as shown in Figure 5. The total delineated area is 3,073,195 ha of which 2,067,624 ha (67%) are under tenure and 1,135,928 ha (37%) are operable. Elevations within the geographic boundaries of G2 range from less than 500 m along the Peace River valley to 1,219 m at Doig Lookout on Halverson Ridge. Within G2, the deployment zone and operational elevations for the white spruce project are 500 to 900 m. As a result, about 18% of the geographic area within Region G2 is excluded (approximately 10% of the area is below 500 m and 8% is above 900 m).

The full range of elevation occurring within the geographic boundary of breeding Region G2 is approximately 750 m, however, areas below 500 m and above 900 m are excluded from the operational zone as the upper boundary represents growing conditions limiting to spruce in terms of summer growing season length and temperature while the lower boundary represents environments limited by growing season drought. The operational range of 400 m (500 to 900 m asl) was chosen in part to accommodate a decline of approximately 0.55 m for the lower and 0.82 m for the upper boundary of the Lower Boreal Highlands Natural Subregion (core area of the breeding region) which occurs for every km of displacement north (Natural Subregion Committee, 2006).

6.2 Forest Cover

Within G2, deciduous dominated forest types cover approximately 60% of the forested land area and coniferous dominated types cover approximately 40% based on phase 3 inventory. On the coniferous land base, coniferous cover types are 40% white spruce, 20% black spruce and 40% pine, as determined by species dominance.

On upland sites, mixed and pure stands of trembling aspen, white and black spruce and pine make up a major portion of the vegetation of this breeding region. Balsam poplar and paper or Alaska birch (*Betula papyrifera* Marsh.) are frequently a stand component on moister sites. Deciduous forest types are more common at lower elevations giving way to mixedwood forests at mid elevations. Conifer forest types dominated by pine occur at the highest elevations. White and black spruce tend to be mid-succession species while balsam fir, which is uncommon due to short fire return intervals, is the climax species. Pines in this breeding region are commonly hybrids between lodgepole and jack pine.

Sandy upland sites and rapidly drained sites at lower elevations are frequently occupied by jack pine. Black spruce occurs on moister upland sites and is extensive in the poorly drained areas. Peatland patterned and unpatterned complexes composed of nutrient poor black spruce bogs often with a tamarack component are common.

6.3 Timber Allocation

The coniferous annual allowable cut (AAC) for this breeding region is essentially fully allocated. A breakdown of total area under tenure, operable area and target strata area for deployment of improved stock is provided in Appendix III.

6.4 Natural Regions, Subregions and Climate

Five natural subregions belonging to the Boreal Forest and Parkland Natural Regions are represented in the breeding region (see Table 6). The majority of the Region G2 area falls within the Lower Boreal Highlands Natural Subregion (67%) and the second largest area falls within the Dry Mixedwood Subregion (24%). Smaller areas fall within the Peace River Parkland (4%), Central Mixedwood (3%) and Upper Boreal Highlands (2%) Natural Subregions. Detailed ecological descriptions of natural regions and subregions including those for plant communities can be found in the "Natural Regions and Subregions of Alberta" report 2006, available on the internet at:
http://www.cd.gov.ab.ca/preserving/parks/anhic/docs/NRSRcomplete%20May_06.pdf

The Lower and Upper Boreal Highlands sections of the breeding region which jointly account for the majority of area, are part of hill systems which begin in British Columbia and extend into Alberta. The adjacent and ecologically similar B.C. portions of these hills occurring in the Alberta Plateau are classified as belonging to upland areas of the Boreal White and Black Spruce (BSBW) Biogeoclimatic Zone and the warm moist variants wm1 and wm2 (Delong, 1990). Some material from this adjacent and ecologically similar area in B.C. has been included in the project under a materials sharing agreement with the British Columbia Ministry of Forests and Range (BC MoFR).

Climate information based on 1961 to 1990 normals and generated by the Alberta Climate Model (Alberta Environment 2005) is provided in Table 6.

Mean annual temperatures in the area decline with latitude and increase with elevation. As mean annual temperature is more highly correlated with winter than summer temperatures, this indicates that milder winters occur at higher elevations (winter inversions).

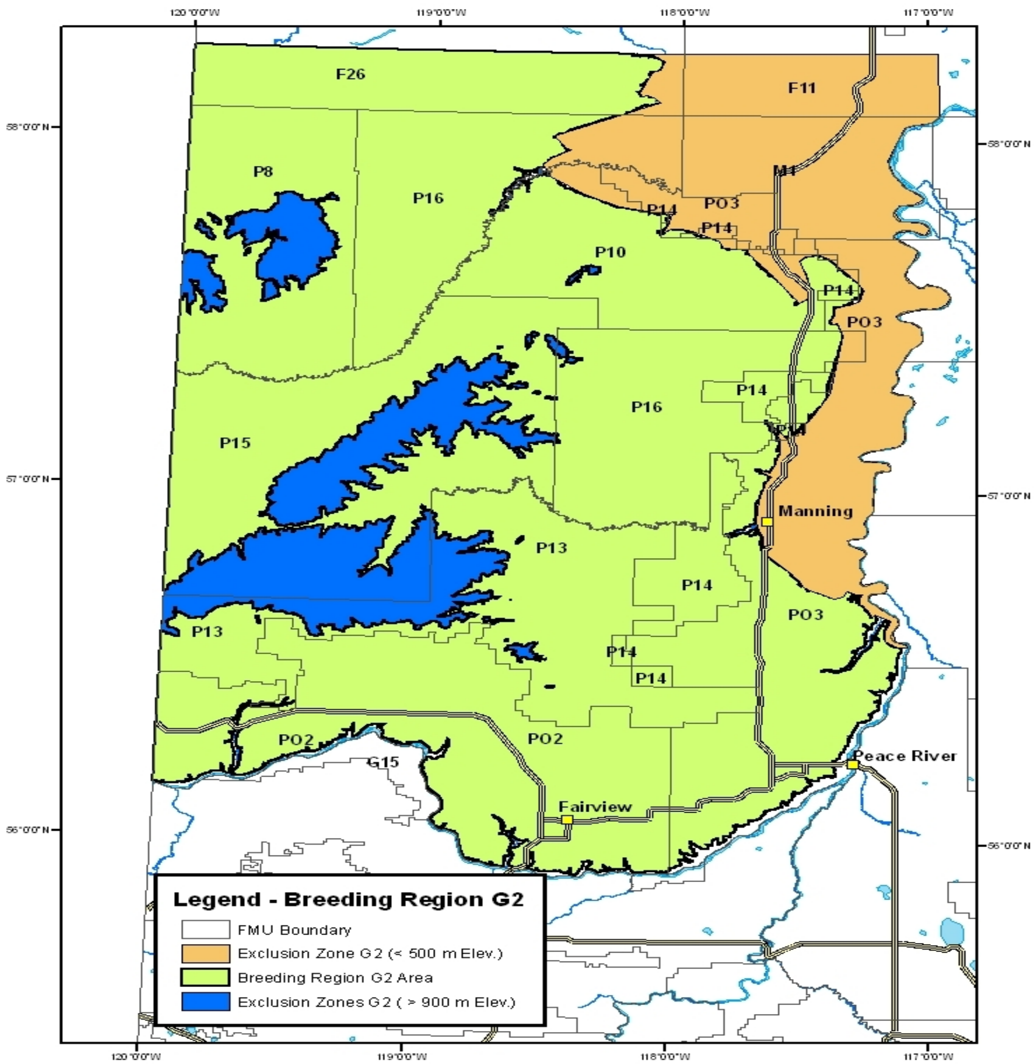


Fig. 13 Breeding Region G2 map showing forest management units and exclusion areas.

The majority of annual precipitation occurs in the form of rain: the monthly maximum occurs in July and two thirds falls during the growing season, April through September. Both growing season precipitation and annual precipitation increase with elevation and latitude. Average growing season precipitation varies from around 250 mm at lower elevations in the south of the region to around 295 mm at lower elevations in the northwest and increases to around 385 mm at higher elevations. Mean annual precipitation follows a similar geographic pattern. Water deficiencies during the late spring and summer can occur throughout the region but are likely not as common at higher elevations where precipitation amounts are higher and growing season temperatures are lower.

Growing season temperatures for Region G2 are highest at low elevations in the south and decrease notably with elevation and more gently with latitude. Growing season thermal climates for natural subregions are represented by growing degree days greater than 5˚C in Table 6 and these are highly correlated with summer temperature variables.

Frost free periods are highly variable and are quite dependent on topographical position. Frost pockets and areas of cold air drainage may have a mean frost free period (FFP) as low as 20 days at higher elevations and around 50 days at lower elevations. Mean FFP for areas in the breeding region not affected by cold air drainage or high radiation loss is about 100 days at lower and mid elevations and somewhat less at higher elevations.

6.5 Physiography and Soils

Breeding Region G2 falls within two major physiographic subregions (Table 6) (Pettapiece 1986). Lower areas of the breeding region, commonly within the Dry Mixedwood Subregion, are classified as belonging to the Northern Alberta Lowlands which consists primarily of undulating morainal plain and areas of level to depressional glaciolacustrine deposits. Parent materials in this subregion are dominantly of clay loam to clay texture and Dark Grey and Orthic Grey Luvisols are the most common upland soils. Significant areas of Gleysolic and Organic soils occur in poorly drained positions. Occasional Brunisols are present on sandy upland sites and there is a substantial area associated with the Peace River Valley which includes steep slopes and terraces of both glacial and modern origin.

Higher elevations in the breeding region, commonly within the Lower Boreal Highlands Natural Subregion, are classified as belonging to the Northern Alberta Uplands. The topography of this subregion is characterized as gently rolling to hilly, morainal uplands. The most common mineral soils are Grey Luvisols and Podzols. In level to depressional areas, organic soils are common and represent approximately 20 to 25% of the total area in the Upland Subregion. A unique area of level to depressional topography lies along the Chinchaga River drainage in the Upland Region where organic soils developed in a peat cap over till and lacustrine deposits cover approximately 60% of the surface area.

An additional small proportion of the breeding region occurring at elevations greater than 1000 m and within areas classified as the Upper Boreal Highlands, is steeply ridged and formed of shallow saprolite deposits and occasional areas of rock outcrops. Dystric Brunisols and Podzols are the most common soils in these areas.

Table 6. Breeding Region G2 climate summary by Natural Subregion.

Natural Subregion	Area (ha)	Area (%)	MAT(˚)	MAP(mm)	GSP(mm)	GDD>5	AMI	FFP(days)
Lower Boreal Highlands	2,064,720	67	-0.9	484	326	1080	2.2	99
Dry Mixedwood	739,000	24	0.3	433	288	1222	2.8	95
Peace River Parkland	111,975	4	1.2	422	282	1340	3.2	104
Central Mixedwood	87,625	3	-0.9	467	317	1156	2.5	97
Upper Boreal Highlands	69,875	2	-1.4	510	341	974	1.9	95
Breeding Region Mean			-0.3	463	311	1155	2.5	98

MAT= Mean Annual Temperature in ˚C
MAP= Mean Annual Precipitation in mm
GSP= Mean growing Season Precipitation in mm
GDD>5= Degree Days accumulation above 5˚C
AMI= Annual Moisture Index (GDD>5/MAP)
FFP= Frost Free Period in days

7.0 BREEDING PLAN FOR THE FIRST GENERATION

The breeding plan chosen for the project consists of phenotypic mass selection in wild stands within the breeding region and establishment of a clonal seed orchard. A small amount of additional genetic material, provided by the BCMoFR from adjacent areas in northeastern British Columbia, is also included after consideration of its adaptability to the G2 region. Genetic testing includes half-sib family (progeny) testing of the seed orchard parents; some additional selections made within the breeding region but not included in the seed orchard design and suitable adjacent region materials available from the ATISC research and conservation collection. A schematic of the breeding plan is shown in Figure. 14. Breeding plan activities and timelines (1995 – 2025) are given in Figure. 15.

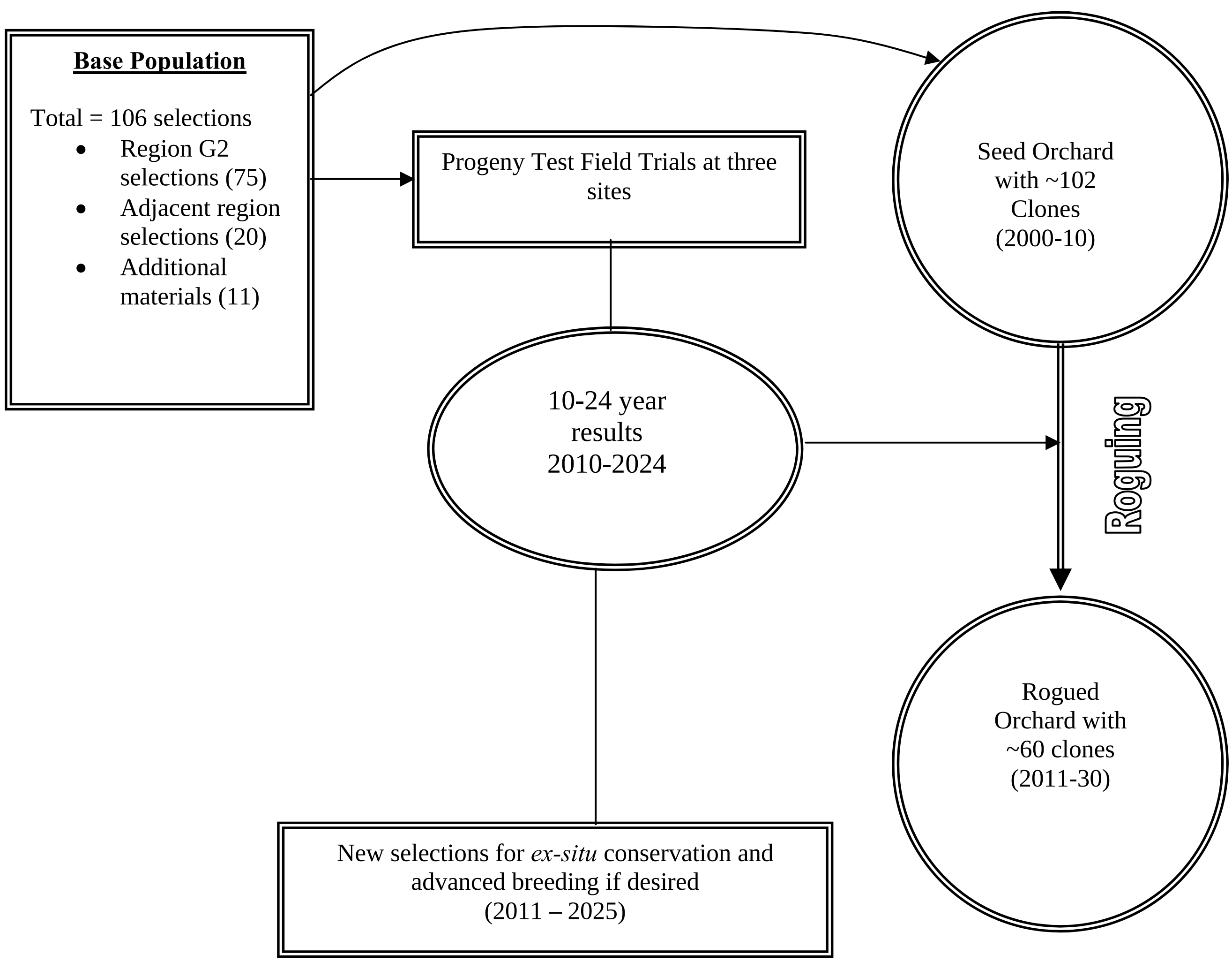


Fig. 14 Region G2 white spruce first generation tree improvement scheme and timelines.

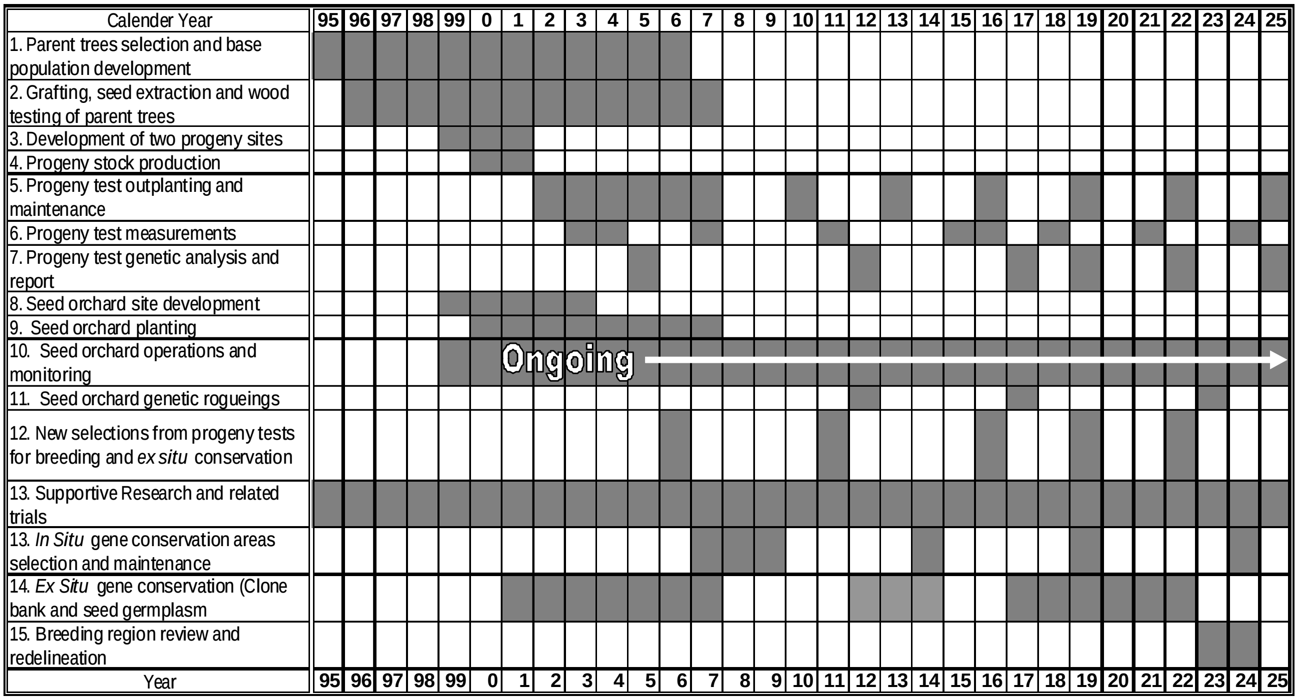


Fig. 15 Region G2 activities and timelines.

7.1 Parent Trees Selection and Base Population Development

Base population genetic stock for the Region G2 project consists of 106 parent trees. Descriptions of the parent tree selections are provided in this section and in Appendix IV.

Genetic stock acquisition to provide base material for the Region G2 tree improvement project dates back to 1980 when parent tree selections commenced for the G1 white spruce project. At that time, Breeding Region G1 extended north, covering a part of the area which now falls into Breeding Region G2 (see Section 2.0 Project History). When the G2 project was initiated in 1995, the ATISC germplasm collection was reviewed for genetic stock adapted to the G2 breeding region. A total of 20 selections, made between 1980 and 1989, were available from adjacent breeding regions (17 from Region G1, 2 from Region H and 1 from Region D1). After reviewing parent tree information with consideration of comparable environments and determining availability of scions and open pollinated progeny seed for genetic testing, these selections were rolled into the project base population.

A comprehensive program of parent tree selections for the G2 project was commenced in 1996 and completed in 1998. As part of this work, a total of 70 parent trees were selected in accordance with the following protocol: a) methodically locate wild stands throughout the breeding region by ground and aerial surveys; b) cruise stands to identify candidate superior trees and document their superiority by the comparison trees method; c) from each tree collect scions for vegetative propagation, wood samples for wood quality testing and cones to provide seed for genetic testing. Wood sample and cone collections continued until 2005. Cone collections were not obtained from seven trees due to the absence of a cone crop or because the tree was logged or destroyed by other industrial activity.

Five trees of G2 geographic origin were selected from the G103G provenance research trial established by ATISC at the Chinchaga River genetics site. These selections, referred to as plantation selections, exhibited desirable phenotypes and had superior height growth when the trial was assessed at age 15 years. Only one tree per seed source, usually the best, was selected. Four forward selections came from the Region G1 half-sib family test established at the Saddle Hills site (G135B). Based on 11-year field performance, all trees in the trial were ranked according to a selection index combining among and within family information. The best tree in each of the top four families was selected. Seven geographic selections were made from adjacent and ecologically similar boreal upland areas belonging to the BSBWwm1 and BSBWwm2 Biogeoclimatic Zones and variants in northeastern British Columbia. Selection of all parent trees detailed above followed standard selection methods and procedures used in ATISC cooperative tree improvement projects. All G2 base population selections (a total of 106) are documented and described in ATISC file reports. There are a total of 12 such reports. The file report reference pertaining to each tree is listed in Appendix IV along with tree accession, tree origin, type of selection, and parent tree superiority information.

The selection criteria and methodology for parent tree selections were as follows.

- Wild stands selections by comparison tree method (also referred to as intensive selections).
  Inventories and other sources of data are reviewed to select promising areas and stands for cruising to select superior trees. Selected stands are geographically spread to sample the target area in a reasonably representative manner and are invariably at least several kilometers apart. They are chosen based on their geographic location and condition: selected stands are well stocked, relatively even aged, healthy, actively growing, in the mid to mature age range, free of significant damage or defects and have good site productivity. Usually, only one tree per stand is selected in order to maximize genetic sampling of the geographic area covered and to minimize the relatedness of selected trees. However, in some cases, two trees can be selected from the same stand if they are at least 50 m apart. Superior trees are selected by the comparison tree method: each selected tree is compared to three dominant trees growing in the vicinity of the selected tree. The selected trees must have superior height growth, an excellent straight stem, average or better dbh and a narrow crown with thin branches; they must be free of any noticeable insect, disease or climate damage. These standards may be relaxed to accommodate circumstances such as exceptional phenotypes for some trait(s) or limited tree selection choice. This was the predominant method for parent tree selections for the G2 project.

- Wild stands selections made by visual selection method (also referred to as geographic selections).
  These selections are made in stands representing a suitable geographic sampling of the breeding region in order to provide genetic materials for the project. The criteria for tree selection may vary from more or less random selection of a healthy dominant tree to selection of a desirable phenotype (straight stem, narrow crown, thin branches, no defects or disease) with superior height. Basic data on the selected tree (age, height and dbh) are collected in most cases but not always. This selection method provides low cost and less time demanding selections to supplement comparison selections and fill in gaps in geographic coverage of the base population. Genetic stock received through other cooperators (e.g. seven trees received from BCMoFR) generally falls under this category.

- Plantation selections.
  These selections are made in field trials established as part of provenance, progeny or family testing projects. The selections are invariably the best trees (top 5 - 10% or better) within the selected provenances or families. The selected trees would generally be young in age (10 – 20 years old) and would have been reviewed by ATISC for adaptation characteristics before being accepted as part of the project base population. Each selected tree is documented with genetic analysis data for the respective provenance, progeny or family for its phenotypic characteristics and breeding value where applicable.

  Currently, selection of parents for the base population for Breeding Region G2 is slightly biased to medium elevation parents and parents south of the breeding region (Figure 16). In terms of natural subregion, the base population is predominantly from the core G2 area belonging to the Lower Boreal Highlands Natural Subregion (Figure 17). Additional parents representing minor natural subregion areas in the breeding region as well as several adjacent analogous natural subregions outside the breeding region are also included.

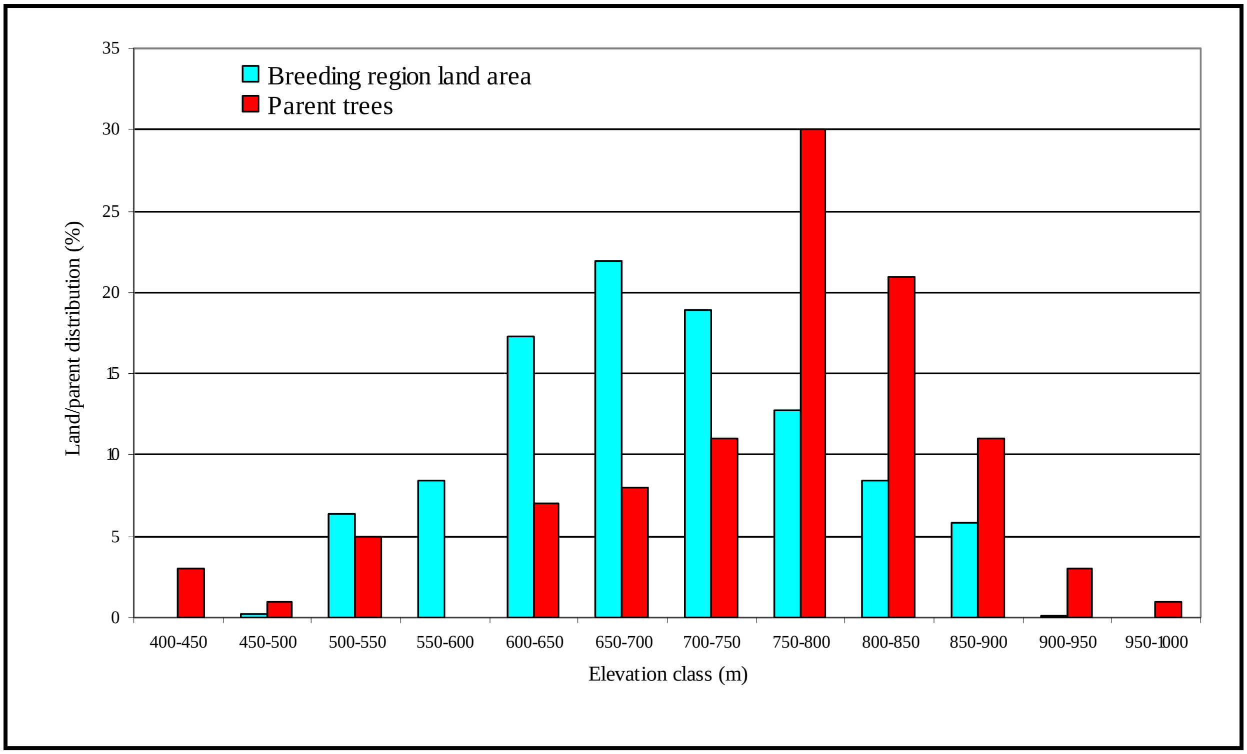


Fig. 16 Distribution of land area and parent trees by elevation in breeding Region G2.

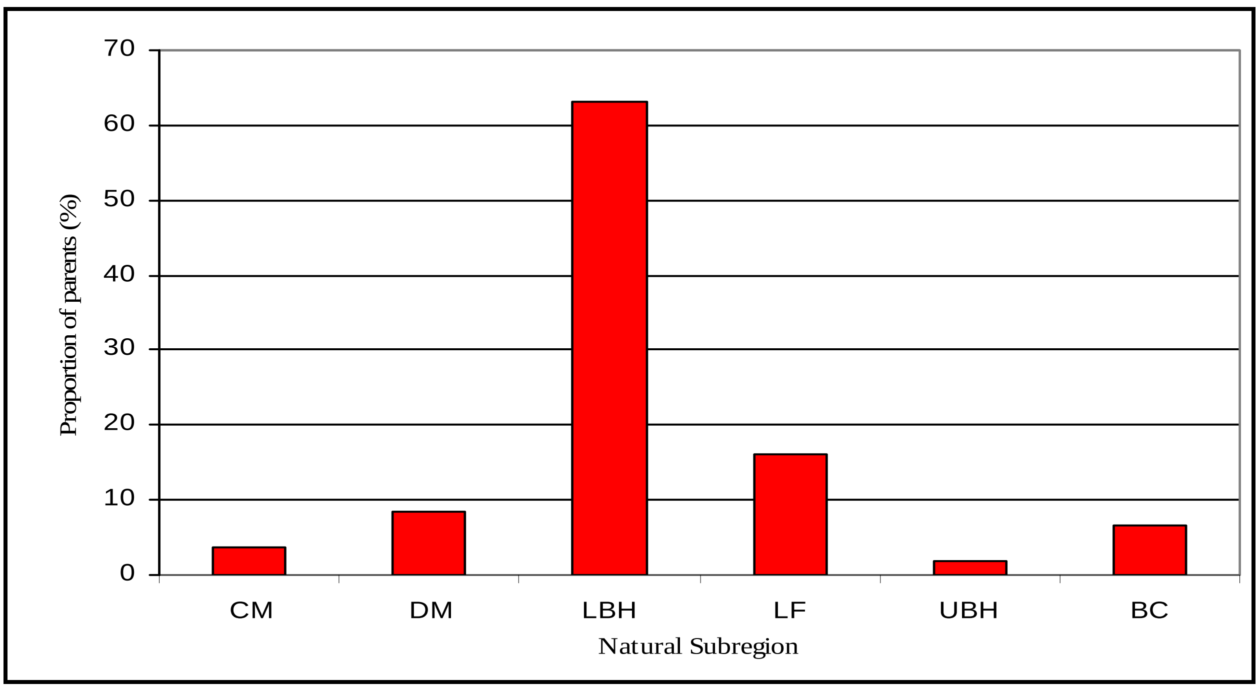


Fig. 17 Distribution of G2 base population by natural subregions.
CM (Central Mixedwood), DM (Dry Mixedwood), LBH (Lower Boreal Highlands) (UBH (Upper Boreal Highlands), LF (Lower Foothills) and BC (Selections from surrounding areas in British Columbia's Boreal White and Black Spruce [BWBS] Biogeoclimatic Zone).

7.2 Genetic Testing

Genetic testing is an integral part of the G2 breeding plan (Figure14). The field trials for this purpose are established at three sites within the breeding region. In addition to the G2 first generation base population progenies, these trials also contain some additional provenance and family materials for research purposes. Some of this material may also be useful for expansion of the base population for advanced selections if second generation breeding becomes desirable for the project.

7.2.1 Test Site Selection, Development and Planting

The three test sites selected were Hotchkiss River, Battle Hill and Sweeney Creek. The Battle Hill test site (G352A) is located in the Boreal Dry Mixedwood Subregion 19 km north and 10 km west of Manning (57°07'N, 117°38'W and 515 m elevation). The Hotchkiss River site (G352B) is located in the Lower Foothills subregion approximately 73 km northwest of Manning (57°08'N, 118°25'W and 750 m elevation). The Sweeney Creek site is located in the Lower to Upper Foothills Subregion transition in the Clear Hills, 55 km west of Worsley (56°34'N, 119°34'W and 915 m elevation). Additional information on site characteristics and history is provided in Table 7 and in the establishment reports of the respective field trials, which also include Test Site Information Forms.

The 3 sites are located within the breeding region boundary and are representative of the white spruce forests in the G2 breeding region: the two predominant natural subregions within the breeding region, Lower Boreal Highlands and Dry Mixedwood, are represented as are the two major physiographic subregions and their associated soil types. The sites also span the operational elevation range of the breeding region (500 - 900 m) and the elevation range of 95% of the base population. The sites selected will allow for assessment of both overall changes in performance and changes in family rank as the trees grow older.

Table 7. G352 series test site descriptions and climates.

Test Site	Ecology and Soils	Original Stand - Site Type	Site Climate				
			MAT ^{0}C	MAP mm	MTCM ^{0}C	GDD >5^{0}C	AMI
Battle Hill (G352A)	Dry Mixedwood subregion; Solonetzic Gray Luvisol with clay loam to clay texture; Moderately well to imperfect drainage	Immature aspen (C2Aw) with some larger aspen and a small component of Sw	-0.3	418	-19.9	1223	2.9
Hotchkiss River (G352B)	Lower Boreal Highlands subregion; Brunisolic Gray Luvisol; fine textured till; Mesic drainage	Pine mixedwood site with overstory consisting of C2PlAw to C3PlAw; UF E1.1 to E2.1 Ecosite	-1.0	500	-19.6	1039	2.1
Sweeney Creek (G352C)	Lower Boreal Highlands subregion; Gley Eluviated Dystric Brunisol; fine textured till (clay loam); Mesic to subhygric, imperfectly drained	The overstory consisted of C3Pl (AwBw)	-0.5	509	-17.5	994	2.0

The sites were logged and prepared during 1997 – 2000 and are enclosed by a game fence. The Battle Hill site is located on wooded farmland owned by MDFP and covered by a land access and use agreement for the G2 project. The Hotchkiss River and Sweeney Creek sites are located on Crown land within the Green Zone and are protected under a Miscellaneous Lease and a DRS land reservation.

7.2.2 Experimental Design, Field Planting and Measurements

The field plantings for genetic testing for the project are referred to as the G352 series field trials or Breeding Region G2 White Spruce Progeny Trials. Three trials were established in the spring of 2002 at Battle Hill (G352A), Hotchkiss River (G352B), and Sweeney Creek (G352C). The experimental design chosen for the three plantings was an Alpha Design (balanced incomplete block design). The trials consist of 138 seedlots in 8 replications with 14 incomplete blocks per replication and 9 or 10 seedlots per block. Seedlots are planted in 3-tree or 4-tree row plots at 2.5 m x 2.5 m spacing.

Of the 106 parents in the G2 base population (see Appendix IV), 86 are represented in the trials. Seed was not available for the remaining 20 parents when the trial was greenhouse seeded in 2001. These are identified in Appendix IV and will be established in a supplementary trial series to be established in 2009 or 2010 after the seed collections are completed from parent ortets in natural stands or from grafts established in the G2 seed orchard. Of the 102 parents in the orchard, 82 are included in the trials.

Although the trials are identified as "Breeding Region G2 White Spruce Progeny Trials", they contain 52 additional research seedlots for reference testing and for linking the results from various white spruce and provenance-family tests in Alberta and northeastern British Columbia. These 52 seedlots include the following material: 8 top performing families from the Northern Areas Provenance OP Family Test (G133B) at the Chinchaga genetics test site; 30 northeastern B.C. selections considered to be potentially promising for the G2 project but requiring adaptation testing; 6 B.C. bulk provenance seedlots; and 8 Alberta bulk provenance seedlots.

The trials were established in early June 2002 using one-year-old dormant container stock (Styroblock 615A, 340 ml). Planting was done using tree planting shovels. Soil moisture during planting at the sites varied from good to excellent. Establishment reports were written for each trial and are on file at ATISC. These are referenced below.

- Establishment Report G352A for Battle Hill site
- Establishment Report G352B for Hotchkiss River site
- Establishment Report G352C for Sweeney Creek site

The plantings are regularly weeded and brushed at 1 - 3 year intervals to keep trees in a free-to-grow condition. Test maintenance will be scheduled for a duration of 40 years. Assessments of the trials were completed at age four years. Survival, plant damage and height were assessed and the results are described in ATISC Technical Report ATISC 05-17 dated June, 2005. A summary of the results for the 124 families included in the tests is provided in Table 8. Briefly, the trials showed excellent overall survival (98.5% – 99.0%). Survival of individual families across sites varied from 95.5% – 100%. Mean height varied from 41.0 cm at Hotchkiss River to 57.1 cm at Battle Hill. Mean height of individual families across sites varied from 42.3 cm to 54.6 cm. Mean damage to seedlings varied from 11.4% at Battle Hill to 41.6% at Sweeney Creek. The most prevalent damage condition was forking possibly due to damage of the terminal shoot followed by loss of apical dominance. Such damage occurs at a seedling stage and is known to be caused by winter or drought-related injuries, insect attack and animal browsing.

Table 8. Means and range of family means for 4-year performance of families in G352 progeny trials.

Trait		Battle Hill	Sweeney Creek	Hotchkiss River	Combined Sites*
Height (cm)	Mean	57.1 ± 0.21	45.2 ± 0.17	41.0 ± 0.20	48.4 ± 0.13
	Range	47.9 – 66.2	37.5 – 52.2	33.0 – 49.5	42.3 – 54.6
Survival (%)	Mean	99.0 ± 0.16	98.7 ± 0.18	98.5 ± 0.23	98.8 ± 0.11
	Range	90.6 – 100	90.6 – 100	87.5 – 100	95.5 – 100
Damage (%)	Mean	11.4 ± 0.50	41.6 ± 0.78	35.0 ± 0.87	28.8 ± 0.43
	Range	0.0 – 31.3	12.5 – 81.3	0.0 – 75.0	13.6 – 50.0

*-Number of common families on all sites is 124.

7.2.3 Future Measurements

The G352 genetic tests will be measured by ATISC at 3 - 6 year intervals up to age 40 in accordance with trial assessment procedures and schedules for white spruce. Assessments are planned for ages 11, 15, 16, 18, 21, 24, 30, 35 and 40. Measured traits will include survival, plant damage condition, white pine weevil incidence and tree height with diameter measurement being added at age 18-years. Wood density assessment with Pilodyn will be done between the age of 27 and 30. In addition, special trait assessments may be carried out on all or a part of the planted materials for research purposes or special tree breeding needs such as adaptation to climate change or pest resistance. The data from trial measurements will be analyzed within 1 - 3 years of the collection date and summarized in an appropriate technical report format.

8.0 SEED PRODUCTION PLAN

Improved seed production to provide a steady and reliable seed supply of white spruce in Region G2 is an essential requirement of the breeding program. The seed produced must meet or exceed genetic adaptation and diversity requirements specified in the STIA. The genetic diversity objective for the orchard is to maintain an effective population size (N_e) of 30 or more in the bulked orchard seedlot averaged over any five year period. The projected annual seed production requirements are estimated to be about 16 kg of seed which should be sufficient to produce about 2.0 million plantable seedlings per year. This calculation is based on the following assumptions: 1000-seed weight = 3.2 g, seed germination ~93% and 2.3 seeds are required to produce one plantable seedling after nursery oversow and seedling culling requirements for quality control are taken into account.

The seed orchard for the G2 project is referred to as the G318 seed orchard. It was established at a site near North Star in 2000. It commenced commercial seed production in 2005 with a sizeable seed crop of 5.7 kg.

8.1 Seed Orchard Site Location and Climate

The Region G2 white spruce seed orchard (G318) is located in the Peace River Dry Mixedwood Plains physiographic subregion at legal land location NW¼ 32-090-23-W5M (56°51'N latitude, 117°38'W longitude, 493 m elevation) just west of North Star on farmland owned by NPARA. NPARA is a farmer owned cooperative interested in applied agricultural research and technology transfer and is interested in cooperating with the G2 forestry project. The location was chosen after reviewing the suitability of 6 potential regional sites. The factors considered were regional climate, soil type, potential for pollen contamination, access, irrigation water availability and labor and equipment availability. The quarter section site was purchased by NPARA, facilitated by a long-term lease agreement for the orchard site which is on a sectioned-off 10 hectare parcel within the site. The term of the lease agreement is 40 years and G2 project partners have the right of first refusal in case the land is sold.

In 1999, NPARA purchased the quarter section of land, which had been under cultivation for the last 40 years. In October 1999, Lansdowne Research & Consulting completed a detailed soil survey and Cridland & Associates Ltd completed a detailed topographic map on the quarter section. Based on these surveys, the most suitable area for the ten hectare orchard site (250 m x 400 m) was the northwest corner of the quarter section. The seed orchard is comprised primarily of Solodic Grey Luvisols (Nampa series) and Solodic Dark Grey Luvisols (Kleskun series). Another soil series found in the quarter section but not within the orchard site was the Goose series, an Orthic Humic Gleysol.

Both the Nampa (Table 9) and Kleskun (Table 10) soil series are upland soils which are very similar in physical and chemical characteristics. The Nampa soil series usually occurs in level to depressional lacustrine deposits with imperfect drainage and slopes ranging from 0 to 0.5%. The series has few stones and the B horizon usually has some mottles indicating poor internal drainage.

Table 9. Characteristic profile and properties of the Nampa soil series.

Horizon	Depth(cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH	OM (%)
Ap	0-15	28.4	42.0	29.6	Clay Loam	6.4	5.5
Ae	15-19	22.4	58.0	19.6	Si. Loam	6.9	2.6
Btn	20-32	18.4	16.0	65.6	H. Clay	6.7	-
BC	32-45	20.4	17.0	62.6	H. Clay	7.0	-
Csk	45+	16.4	18.0	65.6	H. Clay	7.5	-

The Kleskun soil series also occurs in level to depressional lacustrine deposits with imperfect drainage and is very similar to the Nampa series with the exception that there is no mottling in the B horizon usually indicating that it occupies a slope position where surface drainage is better.

Table 10. Characteristic profile and properties of the Kleskun soil series.

Horizon	Depth(cm)	Sand (%)	Silt (%)	Clay (%)	Texture	pH	OM (%)
Ap	0-12.5	27.4	44.0	28.6	Clay Loam	6.5	5.1
Btn	12.5-42.5	26.4	27.0	46.6	Clay	6.0	3.6
BC	42.5-60.5	28.4	34.0	37.6	Clay Loam	7.6	-
Csaca	60.5+	26.4	36.0	37.6	Clay Loam	6.9	-

In November 1999, Battle River Holdings constructed a 32 m x 73 m x 9 m dugout (1.6 million gallons) outside the fence south east of the seed orchard site.

In 2000, the main site development and improvements for the orchard commenced. An 8-foot game fence was erected by Randy Finnebraaten. Two 12-foot gates were installed in the south west and south east corners. In May the entire orchard site was deep ripped to a depth of approximately 24 inches to improve internal soil drainage. After deep ripping, the area was cultivated and harrowed in early July to control weed establishment. In the spring of 2000, an equipment shed shared with NPARA was constructed north of the dugout. On July 10 and 11, a 2-row shelterbelt of Northwest poplar *(Populus x jaackii)* and lilac vilosa *(Syringa villosa Vahl.)* was established along the perimeter of the fence. On July 13 and 14, 455 grafts were planted in the orchard. Root balls were slashed to promote lateral growth and bone meal was incorporated into each planting hole. A knife cultivator was used in late September to control weeds and prepare the area for seeding. In early October, the area was seeded with a mixture of orchard grasses. The local improvement district constructed two approaches in early October to allow access from the west and north of the orchard.

In May 2001, A&D Irrigation from Fort MacLeod designed and installed the drip irrigation system for the orchard site. The site was divided into eight separate zones with two zones each for the spruce and pine orchards and the remaining four zones for expansion. ATCO Electric Ltd. installed single-phase electrical service to the equipment shed in May.

Climate for the site (1961-90) using the Alberta climate model (AENV 2005) is estimated as follows:

- Mean Annual Temperature (°C) 0.1
- Mean Annual Precipitation (mm) 421
- Mean Temperature Coldest Month (°C) -19.2
- Growing Degree Days >5°C 1267
- Annual Moisture Index (GDD/MAP) 3.0

8.2 Orchard Design and Establishment

The G2 orchard was developed through vegetative propagation by grafting of selected parent trees (ortets) described in section 7.1 and Appendix IV. The grafting of trees commenced in 1995. Out of the 106 trees in the base population, 102 are included in the orchard design. Three parents did not graft successfully and one parent was excluded from the orchard because it was found to have heart rot.

The orchard design is permutated neighbourhood and was generated by the SOL 32 computer program with the constraint that any 2 ramets from the same clone be separated by at least 4 ramets of unrelated clones. The orchard design has a total of 800 planting positions at 6 m (among rows) x 3 m (within rows) spacing. Given the number of parents successfully grafted and the size of the orchard, the optimum number of ramets per clone is 8. The nominal maximum number of ramets per clone was set at 10 and the nominal minimum at 6.

Planting in the orchard commenced in July 2000 when 455 grafts were planted and is nearing completion with a total of 793 grafts currently established in 2007. Parent trees are represented by a minimum of 2 grafts and a maximum of 12 grafts per clone. The planting is described in the G318 establishment report dated October 16, 2000 and in annual addenda written each year after that. These reports provide the geographic origin of the orchard trees, field layout maps, planting row and position number of individual ramets, the total number of ramets per clone, the year of planting of each graft and a record of periodic mortality and replacements.

8.3 Orchard Management and Seed Production

In 2007 orchard establishment was nearly complete with 793 grafts planted. Grafts range in age from 4 to 12 years and the average age is 10. The average number of ramets per clone is 8 and the range is 2 to 12. Of the 12 clones with less than the nominal minimum of 6 ramets, the majority (9) had low rates of grafting success. Three of the forward selections from the Region G1 half-sib family test at the Saddle Hills site (G135B) were restricted to a maximum of 3 ramets each because their respective seed parents, selections from Region G1, are also present in the orchard creating the possibility of inbreeding. The 15 clones with ramet numbers greater than the nominal maximum of 10 had exceptional grafting success and 1 to 2 additional ramets per clone were planted to compensate for short falls in other clones.

The imbalance in the number of ramets per clone is not expected to unduly affect the effective population size (Ne) of orchard seedlots: if each clone contributes male and female gametes in direct proportion to the number of ramets representing it, the highest possible Ne with the current imbalance is approximately 94. The maximum Ne possible with an equal number of ramets per clone and equal contribution of gametes from each clone is 102, the number of clones in the orchard. However, the maximum Ne is rarely, if ever, achieved due to imbalances in flower production among clones.

Until 2005, orchard management and operations were carried out by NPARA on a contract basis with technical and scientific support provided by ATISC. Starting in 2006, orchard management was carried out by the FGAA. The main management goals for orchard trees at this stage are growth, development, flowering enhancement, crown management and pest control. In order to achieve these goals, the following management activities are completed on a routine basis:

- Tissue and soil samples are collected annually in the fall to assess nutrient levels and to provide base information for the following year's fertilization regime.
- The prescribed amount of granular fertilizer is applied over three applications throughout the growing season.
- Weeds are controlled by mowing and by the application of herbicides.
- Water is delivered to each tree with a drip irrigation system capable of providing at least 2.3 L of water per hour. The system is flushed each spring and all emitters are checked to ensure that the water is flowing to each tree.
- A comprehensive insect and disease survey is completed every second year and pest control is carried out annually by seasonal pesticide applications or by mechanical means. Grafts are assessed throughout the growing season for the occurrence of insects and diseases but are particularly monitored when infestations of specific insects are known to occur.
- Crown management is carried out on grafts greater than 3 m in height to promote fuller crowns and thereby increase flowering sites and to limit tree height growth. The trees are topped with a pruning saw immediately above an internode with vigorous lateral branches.

In years when a collectible cone crop is produced, all cones are picked by individual tree so that clonal reproductive contribution and effective population size can be determined. Cones are subsequently bulked for extraction. Germination testing is completed on the bulk seedlot. Annual cone and seed production information for the orchard is summarized in Table 11. Orchard management activities are described in detail in the Annual Orchard Management and Operations reports for the G2 orchard. These have been completed annually since 2000 and are on file at ATISC.

Table 11. Cone crop and seed production information Region G2 white spruce clonal seed orchard (G318).

Variable	2007	2006*	2005	2004	2003	2002	2001
Number of trees	793	789	773	742	628	581	520
Average tree age (years from grafting)	10	9	8	7	7	6	6
Trees producing cones	490	-	595 (77%)	101 (14%)	306 (49%)	161 (28%)	15 (3%)
Number of clones	102	-	100	100	95	89	81
Clones producing cones	96	-	96 (96%)	48 (48%)	77 (81%)	54 (61%)	14 (17%)
Cone production (l)	201	-	493	3	84	24.8	0.3
Cones/tree	29	9	153	1	23	9	0.2
Cones/litre	115	149	240	271	168	205	287
Total number of cones	23,078	-	118,313	812	14,149	5,068	86
Clean seed (g)	1,862	-	5,670	0.13	591.7	135.7	0.8
Seeds/cone	33	6.9	25	0.07	17	12.7	4.3
Seeds/kg	413,223	335,570	524,658	438,528	405,712	473,463	444,820
Seed yield (g/hl)	926	313	1150	4.3	704	548	274
1000 seed weight	2.42	2.98	1.91	2.28	2.46	2.16	2.25
Germination %	96	98	93	84	97	89	88.5
Effective population size	39**	-	42	6	29	23	8

*data from psts only

**including 9 clones extracted and stored separately; excluding these clones, Ne is 46

The seed production projections for the orchard were done for the period 2000 to 2027 using pooled data (4-year moving averages) from 5 Alberta white spruce clonal orchards over a 12-year period. These projections, the seed to plantable seedling conversion and the amount of improved stock available to each project partner from the projected orchard production is shown in Table 12.

Referring to the Seed Production and Deployment Plan (Appendix III) and Table 12, it can be demonstrated, using the following assumptions, that the orchard design and deployment objectives are quite well aligned:

- Assume average rotation age of 110 years;
- Assume total target strata for planned deployment of 400,000 ha;
- Assume even-flow harvest;
- Assume a planting density of 1200 trees per ha;
- Assume volume gain is twice height gain.

Annual planting demand will then be 400,000/110 = 3600 ha and annual improved seedling demand will be 50% x 3600 x 1200 = 2.2 million. Assuming a 10% lift in AAC (gain in volume taken in area), the annual seedling demand will be 1.10 x 2.2m = 2.4 million. In comparison, the annual seedling supply is projected to be 2.5 million.

Table 12. G2 orchard seed production estimates and seedlings allocation to project partners.

Year	Graft Age[1]	Actual[2] Production # seeds /Tree	Predicted[3] Production # seeds /Tree	# Trees in Orchard	Total # Seeds[4]	Total # Seeds (Adjusted)[5]	Total[6] Seedling Production	Seedling Allocation to Partners[7]		
								MDFP (72%)	TIHL (4%)	ATISC (24%)
2000	5		0.0	455	0	0	0	0	0	0
2001	6	0.7	0.0	520	0	0	0	0	0	0
2002	6	110.8		581						
2003	7	383.0	0.0	628	0	0	0	0	0	0
2004	7	0.1		742						
2005	8	3826.4	0.01	773	8	7	3	2	0	1
2006	9	61.8	0.3	789	197	178	77	56	3	19
2007	10	960.4	5.5	793	4,362	3,925	1,707	1,229	68	410
2008	11		117.8	800	94,240	84,816	36,877	26,551	1,475	8,850
2009	12		1971.5	800	1,577,200	1,419,480	617,165	444,359	24,687	148,120
2010	13		7066.0	800	5,652,800	5,087,520	2,211,965	1,592,615	88,479	530,872
2011	14		8015.1	800	6,412,080	5,770,872	2,509,075	1,806,534	100,363	602,178
2012	15		8064.7	800	6,451,760	5,806,584	2,524,602	1,817,713	100,984	605,904
2013-2027	16-30		8067.0		6,453,600	5,808,240	2,525,322	1,818,232	101,013	606,077

[1]Average graft age for orchard from cone and seed production table of annual orchard report. Note graft age may be the same in consecutive years because greater numbers of younger grafts were planted in the latter year eg. 2003 and 2004

[2] Calculated from orchard seed production data

[3] Calculated from ATISC Cooperative Sw seed orchards 4-year moving average data and logistic regression of the data for curve smoothing

[4] Seeds/tree in [3] multiplied by number of trees in the orchard

[5] Total number of seed minus 10% upfront seed share for ASRD as per orchard agreement

[6] Total number of seeds in [5] divided by 2.3 (assumes production of 1 plantable seedling requires sowing 2 seeds per cavity and some oversow);

10% seed share for ASRD as part of the seed orchard agreement is not included in this calculation

[7] Total seedling production in [6] proportionately divided among project partners according to their orchard seed share

8.4 Permanent Sample Tree Program, Orchard Phenology and Pollen Contamination Monitoring

In accordance with STIA guidelines, a permanent sample tree (pst) monitoring program was started in the region G2 orchard in 2001. The pst program serves the following purposes: to provide orchard-specific local data on seed orchard development, flowering, cone and seed production and seed quality; to provide an estimate of reproductive contribution of orchard clones; and to serve as a tool for cone crop forecasting and seed collection planning.

There are currently 122 psts assigned in the orchard with each planting year being proportionately represented. This exceeds the sample size stipulated by STIA (10% of the intended number of trees) and provides a buffer in the event of any mortality. Psts are selected systematically to ensure all clones represented by 5 or more ramets are included and to ensure all areas of the orchard are sampled. Data are collected on the following traits: height, crown width, dbh, number of male and female flowers, number of cones, cones per litre, seeds per cone, 1000 seed weight and seed germination. The results are tabulated and summarized each year in the annual orchard management and operations reports. The results of 2007 pst monitoring are shown in Table 13. Currently, psts represent a 15% sample of the orchard and, in 2007, the psts produced about 19% of the estimated cone crop. This suggests that the sampling is good and that a very high proportion of flowers develop into cones.

- Pollen monitoring
  Three wind vane type pollen monitors are installed in the orchard just prior to pollen flight, usually in mid-May. A microscope slide coated with petroleum jelly is mounted on each monitor to trap pollen and the slides are changed every one to two days for the duration of orchard receptivity. The slides are examined under a compound microscope and pollen counts are completed in a defined area of the slide for a prescribed number of samples to determine the average daily and cumulative orchard pollen density in grains/mm^2.

- Pollen contamination
  Outside orchard levels of spruce pollen are measured with two 'regional' pollen monitors located north and west of the orchard. The regional monitors are more than 300 m away from the orchard boundary. Pollen density in grains/mm^2 is determined for the regional monitors as for the within orchard monitors and the ratio of outside to within orchard spruce pollen density provides an estimate of the proportion of contaminant pollen in the orchard.

  In 2004, the first year of monitoring, pollen contamination was estimated at about 70%. This was a year of very poor flowering in the orchard: mean number of male and female flowers per pst was 3 and 1, respectively. In 2005, a year of abundant flowering with the mean number of male and female flowers per pst at 325 and 112, respectively, pollen contamination was estimated at 14%.

  Phenology monitoring: In the spring, orchard phenology is monitored by evaluating and recording male and female bud development on a sub-sample of the psts in order to develop information on the timing and duration of pollen dissemination and female flower receptivity in the orchard. Each clone in the orchard with five or more ramets is sampled. Female and male bud development stages are assessed approximately every two days beginning when most reproductive buds are identifiable and continuing until all sample trees are post-receptive and pollen has flown. Phenology monitoring is done in years when a collectible crop is anticipated and data are collected for a minimum of five years after full orchard establishment. This information permits the identification of clones that are receptive or shedding pollen earlier or later than the majority of orchard clones. In conjunction with pollen monitoring, phenology data are used to relate patterns of within-orchard pollen flight to the period of orchard receptivity and to identify clones that may be unable to cross with all other clones in the orchard population. Phenology data on individual clones in the G2 orchard is not yet available but phenological variation may be an important issue: data from ATISC spruce orchards suggest that a small number of parents may be unable to cross due to lack of synchrony in flowering.

- Paterniy analysis of seed orchard crops

  Recently, diagnostic chloroplast DNA markers have been developed for paternity analysis of white spruce which provides a powerful means of quantifying pollen contamination in white spruce seed orchards. Using cpDNA extracted from dormant bud tissue, all seed orchard parents are haplotyped using a set of five markers (loci) specific to spruce. Background stands or plantations that are likely sources of contaminant pollen are also sampled to estimate the frequency of haplotypes common to both the background stands and the orchard. Seeds from a given orchard seedlot are then haplotyped using cpDNA isolated from seed embryos. Seed embryos can be defined as either detectable contamination (i.e., genotypes not present in the orchard) or as within-orchard pollination events adjusted for the presence of orchard genotypes in the background pollen. This provides a much more robust measure of pollen inflow from sources outside an orchard than pollen trapping on orchard and regional monitors.

  CpDNA markers can also provide information on orchard pollen dynamics and its impact on seedlot makeup. Pollen contribution to a seedlot can be expressed as the proportion of seed embryos carrying an identical parental haplotype; pollen parent contributions that seriously violate panmixis indicate reductions in effective population size. Sampling and haplotyping seed by clone provides a means of determining interactions between specific male and female parents i.e., some paternal haplotypes may show enhanced fertility with individual maternal clones. Such analyses will supply much of the information that phenology monitoring is intended to provide.

  Currently, all orchard parents but two are haplotyped; from these 100 parents, 55 distinct haplotypes were detected, 39 of them unique to one parent. (Newton 2007). Collections from background stands or plantations that are likely sources of contaminant pollen are planned in 2007/08.

Table 13. Summary of 2007 seed production and monitoring information for Region G2 white spruce clonal seed orchard (G318).

	ORCHARD CHARACTERISTICS	RESULT
1	Orchard design capacity	800
2	Total no. of seed trees established	793
3	Total no. of clones/families established	102
4	Average age	10
5	Age range	4-12
6	Average height (cm ± SE)	-
7	Height range	-
8	Average crown width (cm ± SE)	-
9	Crown width range	-
10	Average DBH (cm ± SE)	-
11	DBH range	-
12	Total no. of PSTs	122
	REPRODUCTIVE BALANCE	
13	No. of PSTs flowering	100
	Male Flowering	
14	No. PSTs with male flowers	88
15	Mean no. male flowers/PST	40
16	Standard error of (15.)	6
17	Range male flowers/PST	0-300
	Female Flowering	
18	No. PSTs with female flowers	80
19	Mean no. female flowers/PST	19
20	Standard error of (19.)	3
21	Range female flowers/PST	0-150
22	Mean male:female flower production ratio	8.4
	IMMATURE CONE PRODUCTION	
23	Date assessed	Na
24	No. PSTs producing cones	Na
25	Mean no. cones/PST	Na
26	Standard error of (25.)	na
27	Range of cones/PST	na
28	**Cone crop estimate (number cones)***	15067
29	**Cone crop estimate (hectolitres)****	1.0
	CONE PRODUCTION	
30	No. of PSTs producing cones	80
31	Mean no. cones/PST	37
32	Range of cones/PST	0-694
33	Total no. of cones collected from PSTs	4565 (all cones)
34	Mean no. of cones/litre***	115
	SEED PRODUCTION * **	
35	Seed production (g)	1862
36	No. of seeds/cone	33
37	1000 seed weight	2.42
38	Germination %	96

* For all species except pine (2.) x (19.)
* For pine species (2.) x (25.)
** To estimate hectoliters divide (28.) by the appropriate factor…
… For white spruce 15000 cones/hl … For black spruce – 24000 cones/hl … For lodgepole pine – 3800 cones/hl
*** For producing orchard, lines 34-38 may be completed from operational crop data

9.0 GENE CONSERVATION

Conservation of wild forest genetic resources is an important part of the G2 white spruce improvement program. Both *in situ* and *ex situ* conservation will be carried out as part of the project in accordance with the Provincial Gene Conservation Plan (ASRD 2007).

In situ gene conservation involves protecting representative populations of white spruce on-site within its natural habitat in the breeding region and in accordance with STIA standards. Populations of white spruce identified for conservation will be selected based on STIA requirements for *in situ* conservation of species covered under CPP programs and in accordance with the provincial Gene Conservation Plan for Native Trees of Alberta. Identification, selection, documentation management and protection of these stands will be a cooperative effort between company partners, Alberta Sustainable Resource Development (ASRD) and Alberta Tourism, Parks, Recreation and Culture (ATPRC).

Ex situ gene conservation involves conserving seed and vegetative germplasm of white spruce outside its natural habitat to complement *in situ* conservation. This will be limited to wild forest collections only and is already ongoing in cooperation with ATISC. Eighty-three seedlots already collected from parent trees in the G2 base population have been conserved in the seed bank and collections from the remaining 20 trees will be completed over the next few years. In addition, 257 grafts from 69 parent trees are established in the white spruce clone bank at ATISC. The G352 progeny test field trials at 3 sites described in section 7.2.2 will also serve as *ex situ* conservation plantings for the duration (40 years) of the trials. Plant materials in field trials discussed in Supportive Research and Field Trials (Section 10.0) will also partially fulfill *ex situ* gene conservation objectives. Efforts will also be continued to select and conserve, by seed collections or vegetative propagation, wild forest germplasm from trees and stands with rare or special characteristics.

10.0 SUPPORTIVE RESEARCH AND FIELD TRIALS

A modest program of applied research to fulfill scientific information needs for the Region G2 breeding project will be carried out with the support of ATISC and the Manning Forestry Research Fund (MFRF) where there is MFRF research project approval. However, with respect to this CPP plan, the work will be limited to project specific knowledge and information needs addressing adaptation, genetic diversity, improved stock deployment, breeding region verification and gene pool conservation. Much of the proposed work will be based on the studies to be carried out in the seed orchard (G318) and progeny trials (G352 series) established as part of the G2 project. In addition, the following white spruce field trials established in the G2 breeding region by ATISC and its cooperators are of interest for scientific studies related to the project.

- G103G White Spruce Provenance Trial
  Established at the Chinchaga River experimental site in 1982, the trial contains 28 Alberta white spruce provenances. It was measured at age 12-years and at 3-year intervals after that to age 27. The trial is one of a province-wide series of 8 white spruce provenance trials.

- G133B White Spruce Northern Areas Provenance-Family Trial
  Established at the Chinchaga River Experimental Area in 1988, the trial contains 125 OP half-sib families sampled from 23 stands across northern Alberta. The purpose of the trial is to study white spruce genetic variation and the adaptation of populations to regional geography and climate. The trial has been measured at 15, 18 and 21-years of age. There are 2 other trials in this series (G133A and G133C) established at the HRA and Red Earth Experimental sites.

- G135A White Spruce Progeny Trial for Region G
  Established at the Chinchaga River Experimental area in 1988, the trial contains 69 half-sib families collected from parent trees selected within the original Region G, now divided into Regions G1 and G2. The trials have been measured at 15, 18 and 21 years of age. These families are represented in one other trial (G135B) established at the Saddle Hills Experimental area.

- G347B White Spruce Provenance and Family Testing – B.C., Quebec and Alberta Materials
  Established at the Battle Hill site in 2001, the trial contains 88 seedlots (32 bulk collections and 56 single tree collections) from British Columbia, Quebec and Alberta. The Quebec material represents the 20 best families in Quebec's white spruce breeding program. This material is represented in 1 other trial (G347A) established at the Diamond Hills Experimental area near Rocky Mountain House.

The results from the above trials have been periodically described in ATISC technical reports and included in Manning Forestry Research Fund annual progress reports from 1996 – 2006. Results are also briefly summarized in Table 4.

The proposed research for the G2 project would make use of the information and data available from all the trials mentioned above and other trials to develop knowledge and increase understanding in the following specific areas.

- Seed Orchard Management and Seed Production
  Flowering and seed production in the G318 seed orchard will be monitored on a regular basis to develop information on seed production, seed supply, pollen contamination and seed losses due to insects, diseases and climatic injury. Although it is considered to be isolated from significant wild white spruce stands and pollen contamination sources by approximately 10 km, pollen contamination needs to be studied and its impact on the genetic quality and adaptation characteristics of G2 seed evaluated as isolated trees and stands occur to the west along an adjacent creek and occur in farm shelterbelts in the area. Other areas of research include orchard cultural practices, crown management, reproductive biology, supplemental pollination, genetic diversity of seed crops and cone and seed insects and diseases.

- Genetic Diversity and Adaptation
  The base population genetic stock for the breeding program is largely local in origin and considered to be adapted to the regional climate. Nevertheless, Breeding Region G2 is quite variable in topography and climate and detailed information is required on regional differentiation of white spruce populations, particularly information on genetic variation in adaptive traits and the role played by climate and geography. Most of this information will be developed using data from the field experiments described earlier but some supplemental field or laboratory studies may also be established. This information will assist in decisions relating to seed source selection, improved stock deployment, genetic conservation and maintenance of forest health.

- Genetic Selection and Breeding
  Breeding values, genetic stability and rankings of individual parents and families will be determined to facilitate selection and breeding for growth, wood quality, climatic hardiness and pest resistance. Genetic gains will be estimated as per STIA requirements. This information will also be used to revise or modify the project concept and as a basis for second-generation breeding should this be desired at a later stage.

- Breeding Region Verification and Adjustments
  The present delineation of Region G2 is mainly based on vegetation, ecology, climate and forest planning considerations. Genetic information was taken into account only indirectly as very little empirical information was available at the time of project planning in 1995. The main tree improvement objective in breeding region delineation is to identify a target environment for deployment of improved seed varieties developed through selection and breeding where field performance is relatively stable and genotype by environment interaction is minimized. Information to verify the appropriateness of the breeding region boundary will be developed through analyses of data from the field trials described earlier and will be evaluated along with similar information from the neighboring white spruce breeding regions i.e. Region H to the north, Region D1 to the east, Region G1 to the south and the Peace Plateau seed planning zone to the west in British Columbia. Re-delineation of the breeding region (expected to be done around 2025) will also take into account climate change information and examine second generation breeding, if desired.

11.0 ACKNOWLEDGEMENTS

This report was developed by a team ATISC staff with assistance from company cooperators. A part of the work described in the report was funded by the Manning Forestry Research Fund.

12.0 LITERATURE CITED

AARD (Alberta Agriculture and Rural Development). 2005. Agricultural Land Resource Atlas of Alberta – Frost-Free Period of Alberta 1971 to 2000. Available at: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10304

AFLW (Alberta Forestry, Land and Wildlife) 1985. Alberta phase 3 forest inventory: An overview. ENR Report No. I/86. Edmonton.

ASRD 2005. Standards for Tree Improvement in Alberta. Publ. No. T/079. Alberta Sustainable Resource Development. Edmonton.

ASRD (Alberta Sustainable Resource Development). 2007. Gene Conservation Plan for Native Trees of Alberta. Working Group on Native Tree Gene Conservation in Alberta (Alberta Sustainable Resource Development and Alberta Tourism, Parks, Recreation and Culture). Publication No. T/141. 107pp.

Alberta Environment. 2005. Alberta Climate Model (ACM) to provide climate estimates (1961 – 1990) for any location in Alberta from its geographic coordinates. Publ. No. T/749. Alberta Environment. Edmonton.

Burr, K. E., Tinus, R. W., Wallner, S. J. and King, R. M. 1990. Comparison of three cold hardiness tests for conifer seedlings. Tree Physiol. 6: 351-369.

Delong. C. 1990. A field guide for identification and interpretation of ecosystems of the northeast portion of the Prince George Forest Region. Res. Br., B.C. Min. For., Victoria, B.C. Land Management Handbook, ISSN 0229-1622; no. 22.

Dhir, N. K., Barnhardt, L. K., Hansen, C., Rweyongeza, D. and Quinn, J. 2007. Applied forest genetics research and practical tree breeding to enhance growth, yield, timber quality and pest hardiness of future forests in the Peace Region. Project Progress Report 2006/2007 submitted to Manning Forestry Research Fund. Technical Report ATISC 07-20.

Furnier, G. R., Stine, M., Mohn, C. A. and Clyde, M. A. 1991. Geographic pattern of variation in allozymes and height growth in white spruce. Can. J. For. Res. 21: 707-712.

Hall, J. P. 1986. Provenance trial of white spruce in Newfoundland: Twenty five years from seed. Can. For. Serv., Newfoundland Res. Cent. Inf. Rep. N-X-247.

Kiss, G. K and Yanchuk, A. D. 1991. Preliminary evaluation of genetic variation of weevil resistance in interior spruce in British Columbia. Can. J. For. Res. 21: 230-234.

Khalil, M. A. K. 1986. Variation in seed quality and juvenile characters of white spruce (*Picea glauca* [Moench]) Voss). Silvae Genet. 35: 78-85.

Li, P., Beaulieu, J. and Bousquet, J. 1997. Genetic structure and pattern of genetic variation among populations in eastern white spruce (*Picea glauca*). Can. J. For. Res. 27: 189-198.

Natural Regions Committee 2006. Natural Regions and Subregions of Alberta. Compiled by D.J. Dowing and W.W. Pettapiece. Government of Alberta. Pub. No. I/005.

Newton, C. 2007. Summary of Chloroplast DNA haplotyping in Alberta spruce seed orchards. Unpublished Project Progress Report submitted to Alberta Sustainable Resource Development.

Nienstaedt, H. and A. Teich. 1971. The Genetics of White Spruce. U.S.D.A. Forest Serv. Res. Pap. WO-15, 24 pp.

Nienstaedt, H. and Riemenschneider, D. E. 1985. Changes in heritability estimates with age and site in white spruce, (*Picea glauca* [Moench] Voss). Silvae Genet. 34: 34-41.

Nienstaedt, H. and J.C. Zasada. 1990. Picea glauca (Moench) Voss: White Spruce. *In* R.M. Burns and B.H. Honkala (Tech. Coord.). Silvics of North America: Vol.1 – Conifers: 389 -442. Agricultural Handbook 654. USDA, Forest Service. Washington, DC.

Pettapiece, W.W. 1986. Physiographic subdivisions of Alberta. Res. Branch, Agr. Canada, Ottawa, Ontario. Map at 1:1,500,000

Rweyongeza, D. M. and Yang, R-C. 2005. Genetic variation, genotype by environment interaction and provenance response to climatic transfer for white spruce (*Picea glauca* [Moench] Voss) in Alberta. Project Progress Report 2003/2004 submitted to Alberta Environment and Sustainable Resource Development. ATISC File Report 05-03.

Rweyongeza, D.M., R-C. Yang, N.K. Dhir, L.K. Barnhardt, and C. Hansen. 2007. Genetic variation and climatic impacts on survival and growth of white spruce in Alberta, Canada. Silvae Genet. 56: 117-127

Stellrecht, J. W., Mohn, C. A. and Cromell, W. M. 1974. Productivity of white spruce seed source in a Minnesota test planting," Minnesota Forestry Research Notes, No. 251, 4 pp.

Tebbetts, R. P. 1981. Early results of an Ottawa Valley white spruce provenance test planted in Maine. *In* Proceedings of the 2nd North Central Tree Improvement Conference, 5-7 August 1981, Lincoln Nebraska. University of Wisconsin, Madison. P 140-146.

Teich, A. H., Morgenstern, C. K. and Skeates, D. A 1975. Performance of white spruce provenances in Ontario. Petawawa Forest Experiment Station. Canadian Forest Service, Environment Canada, and Forest Research Branch, Division of Forests, Ontario Ministry of Natural Resources. Petawawa and Ontario Special Joint Report No. 1.

Appendix I Provenances Used in the Canada-wide Provenance Trial Established in Alberta in G103RW (G276 and G277 series)

ACC#	ID	Location	LAT	LONG	ELEV
0002	A2	Footner Lake (AB)	58°44’	117°15’	335
0004		Walkin Tower (AB	57°55’	115°30’	360
0010	A10	Atabasca Forest (AB)	59°53’	111°43’	183
0012	A12	Lac La Biche Forest (AB)	54°38’	110°13’	610
0015	A15	Slave Lake Forest (AB)	56°38’	114°35’	731
0019		Slave Lake (AB)	55°29’	116°05’	610
0021	A21	Footner Lake (AB)	57°36’	117°31’	460
0023	A23	Peace River (AB)	56°34’	119°40’	762
0032		Edson	53°15’	117°28’	1036
0034		Edson	53°19’	117°51’	1067
0042		Rocky/Clearwater (AB)	52°43’	115°25’	1036
0446		Cypress Hills Park (AB)	49°38’	110°14’	1310
0784		Steen River (AB)	59°32’	117°13’	305
2416		Slavey Creek (AB)	59°05’	117°40’	335
3240		Edson (AB)	52°40’	115°30’	1067
1314	14	Goosebay (NF)	53°20’	60°25’	30
1315	15	Pasenda (NF)	49°01’	57°37’	45
1317	17	St. Ann’s (NS)	46°16’	60°37’	137
1319	19	Earlton (NS)	45°34’	63°10’	150
1320	20	Edmunston (NB)	47°27’	68°12’	198
1321	21	Upper Green River (NB)	47°50’	68°21’	304
1325	25	Clapperton TwP (QE)	48°25’	66°15’	487
1327	27	Dasserat TwP (QE)	48°13’	79°29’	289
1328	28	Chicoutimi (QE)	48°05’	71°09’	594
1329	29	Cimon TwP (QE)	48°17’	71°00’	198
1330	30	McGill TwP (QE)	46°15’	75°35’	304
1331	31	Laurentides Pk (QE)	47°30’	71°00’	792
1333	33	Havelock (ON)	44°26’	77°50’	180
1334	34	Forester’s Fall (ON)	45°41’	76°48’	137
1335	35	Burt Twp (ON)	48°02’	80°22’	300
1336	36	Waweig Lake (ON)	50°09’	89°07’	305
1337	37	Carmat (ON)	49°36 ’	89°09’	305
1338	38	Twist Lake (ON)	49°22’	89°45’	425
1340	40	Kenora (ON)	49°45’	94°46’	365
1341	41	Dryden (ON)	49°42’	93°30’	396
1344	44	Red Lake (ON)	51°02’	93°48’	365
1346	46	Timmins TwP (ON)	48°18’	80°42’	900
1349	49	Osnaburgh (ON)	51°12’	90°12’	365
1350	50	Kapuskasing (ON)	49°18’	82°42’	900
1351	51	Lake. St. George (MN)	51°25’	96°25’	243
1352	52	Angle Inlet (MN)	46°19’	95°20’	335
1353	53	West Hawk Lake (MN)	49°47’	95°15’	335
1354	54	Bernic Lake (MN)	50°25’	95°36’	274
1355	55	Minago River (MN)	54°10’	99°10’	243
1356	56	East Braintree (MN)	49°42’	95°35’	335
1357	57	Gold Ck (MN)	51°04’	95°47’	304
1358	58	Mid-Interlake (MN)	52°12’	98°47’	274
1360	60	Candle Lake (SK)	53°55’	104°50’	502
1361	61	Candle Lake (SK)	53°45’	105°12’	494
1362	62	Besnard Lake (SK)	55°19’	106°05’	401
1363	63	Old Channel River (SK)	53°55’	102°23’	266
1365	65	Madge Lake (SK)	51°38’	101°40’	621
1366	66	Dore Lake (SK)	54°42’	107°16’	485
1369	69	Ft. St. James (BC)	54°28’	124°15’	701
1370	70	Gagnon CK (BC)	55°15’	123°05’	914
1371	71	Bell Arving R. (BC)	56°20’	129°15’	457
1373	73	McDame Post (BC)	59°10’	129°15’	762
1374	74	Ground Birch Ck. (BC)	56°30’	122°10’	823
1376	76	Alex Graham Mt. (BC)	52°05’	122°56’	1280
1378	79	P.F.E.S. (ON)	45°58’	77°26’	170
1379	79	Rankin (ON)	45°45’	77°10’	152
1380	80	Ft. Smith (NWT)	66°02’	111°58’	182
1381	81	Whitehorse (YK)	60°00’	135°08’	762
1382	82	Davis Mills (ON)	45°45’	77°12’	152
1383	83	Douglas (ON)	45°30’	77°01’	121
1384	84	Forester Falls (ON)	45°41’	76°48’	140
1385	85	Burwash Land (YK)	61°21’	139°00’	792
1386	86	M.I.E. Dawson (YK)	64°04’	139°00’	609
1387	87	Carmacks M1001 (YK)	62°03’	136°14’	533
2409		Peace River (AB)	56°03’	118°05’	609
3078		Marchland (MN)	49°26’	96°23’	1007
3079		White Shell Prov. Pk (MN)	50°05’	95°48’	1100
3080		Bissett (MN)	51°00’	96°00’	270
3081		Manigotagan (MN)	50°57’	96°16’	230
3083		Bloodvien River (MN)	52°00’	96°00’	224

ID –number used in the scatter plots.

Appendix II Locations and Climatic (1961 – 1990) Description for Populations and Test Sites in the Alberta White Spruce Provenance Trials (G103)

ACC#	ID	Location	LAT.	LON.	ELEV	MAT	TCM	NDD	TWM	GDD	CI	MAP	AMI
			(°N)	(°W)	(m)	(°C)	(°C)		(°C)		(°C)	(mm)	
Populations													
0002	2+	Footner Lake	58°44'	117°15'	335	-1.6	-21.9	-2668	16.0	1190	37.9	408	2.9
0003	3	Footner Lake	57°55'	117°55'	305	-0.3	-20.8	-2371	16.4	1303	37.2	401	3.2
0004	4+	Footner Lake	57°55'	115°30'	360	-0.4	-20.9	-2353	16.3	1275	37.2	428	3.0
0005	5	Footner Lake	58°33'	114°14'	235	-1.0	-21.9	-2502	16.3	1239	38.2	370	3.3
0006	6+	Athabasca	58°44'	111°15'	235	-1.7	-23.9	-2759	16.9	1242	40.8	386	3.2
0007	7	Athabasca	58°12'	111°23'	229	-0.9	-22.5	-2554	17.3	1330	39.8	417	3.2
0008	8+	Athabasca	57°08'	111°38'	274	-0.2	-21.1	-2351	16.9	1340	38.0	439	3.1
0009	9	Athabasca	56°38'	111°10'	370	0.2	-19.7	-2203	16.6	1320	36.3	473	2.8
0010	10+	Athabasca	59°53'	111°43'	183	-2.6	-25.2	-2984	16.7	1174	41.9	331	3.5
0011	11	Lac La Biche	54°22'	110°45'	550	0.8	-18.4	-2035	16.4	1351	34.8	418	3.2
0012	12+	Lac La Biche	54°38'	110°13'	610	0.6	-18.0	-2039	16.2	1300	34.2	462	2.8
0013	13	Lac La Biche	54°58'	112°10'	551	1.3	-16.8	-1835	16.1	1310	32.9	503	2.6
0014	14	Lac La Biche	55°13'	113°12'	610	1.0	-17.4	-1889	15.9	1261	33.3	482	2.6
0015	15+	Slave Lake	56°38'	114°35'	731	-0.1	-17.5	-2054	14.8	1083	32.3	439	2.0
0016	16+	Slave Lake	54°48'	116°59'	731	2.5	-12.7	-1432	15.6	1294	28.3	553	2.3
0017	17+	Slave Lake	55°14'	114°46'	610	1.5	-15.0	-1701	15.7	1259	30.7	520	2.4
0018	18	Slave Lake	54°32'	114°05'	640	1.6	-15.5	-1725	15.9	1291	31.4	509	2.5
0019	19	Slave Lake	55°29'	116°05'	610	1.4	-16.4	-1794	15.8	1287	32.2	481	2.7
0020	20	Slave Lake	55°46'	113°18'	579	0.8	-17.7	-1946	16.0	1263	33.7	509	2.5
0021	21+	Peace River	57°36'	117°31'	460	-0.5	-20.6	-2340	15.8	1223	36.4	443	2.8
0022	22	Peace River	56°59'	117°50'	610	-0.3	-19.3	-2230	15.4	1174	34.7	445	2.6
0023	23+	Peace River	56°34'	119°40'	762	-0.2	-18.0	-2101	14.7	1086	32.7	454	2.4
0024	24	Peace River	56°28'	118°05'	823	-0.1	-17.4	-2073	14.8	1114	32.2	480	2.3
0026	26	Grande Prairie	55°35'	119°35'	838	0.8	-15.0	-1771	14.5	1104	29.5	522	2.1
0027	27+	Grande Prairie	55°35'	118°18'	640	1.6	-15.7	-1747	15.8	1320	31.5	483	2.7
0028	28	Grande Prairie	55°08'	117°17'	667	2.4	-13.9	-1528	16.1	1365	30.0	490	2.8
0029	29+	Grande Prairie	54°27'	117°38'	940	1.8	-13.9	-1474	14.5	1112	27.4	611	1.8
0030	30	Grande Prairie	54°38'	117°57'	990	1.6	-12.9	-1507	14.3	1088	27.2	614	1.8
0031	31+	Edson	53°46'	118°48'	1402	0.7	-11.7	-1462	12.1	773	23.8	627	1.2
0032	32+	Edson	53°14'	117°28'	1342	1.5	-11.4	-1372	13.3	932	24.7	601	1.6
0034	34	Edson	53°19'	117°51'	1067	2.4	-10.7	-1232	14.2	1079	24.9	566	1.9
0035	35	Whitecourt	53°39'	115°42'	838	1.7	-13.7	-1547	14.8	1166	28.5	568	2.1
0036	36	Whitecourt	54°16'	115°18'	762	1.8	-13.9	-1574	15.3	1219	29.2	535	2.3
0037	37+	Whitecourt	54°11'	116°37'	945	2.3	-11.1	-1341	14.8	1159	25.9	591	2.0
0038	38	Whitecourt	54°22'	114°40'	610	1.9	-11.1	-1647	16.0	1327	31.0	480	2.8
0039	39	Roc/Clearwater	52°33'	115°30'	1067	2.4	-15.0	-1304	14.8	1153	26.2	610	1.9
0040	40+	Roc/Clearwater	52°10'	115°28'	1341	1.4	-11.5	-1380	13.2	911	24.7	620	1.5
0041	41	Roc/Clearwater	52°00'	115°15'	1280	1.8	-11.1	-1294	13.3	947	24.4	624	1.5
0042	42	Roc/Clearwater	52°43'	115°25'	1036	2.5	-11.6	-1328	15.1	1205	26.7	614	2.0
0043	43	Roc/Clearwater	52°55'	115°47'	1067	2.2	-11.8	-1367	14.8	1161	26.6	618	1.9
0045	45	Bow/Crow	50°48'	114°36'	1463	2.0	-9.8	-1201	13.2	921	23.0	599	1.5
0046	46+	Bow/Crow	51°24'	115°13'	1600	0.8	-11.5	-1466	12.5	807	24.0	593	1.4
0047	47	Bow/Crow	50°05'	114°30'	1830	0.8	-10.3	-1407	12.5	780	22.8	689	1.1
0048	48+	Bow/Crow	49°39'	114°37'	1585	2.2	-9.2	-1168	13.6	943	22.8	756	1.2
0446	446+	Cypress Hills	49°38'	110°14'	1310	2.4	-11.7	-1375	15.7	1243	27.4	484	2.6
0782	784+	Footner Lake	59°32'	117°13'	305	-2.3	-23.6	-2874	15.9	1171	39.5	382	3.1
Test Sites													
B		Hay River	59°08'	117°34'	370	-2.3	-23.1	-2862	15.7	1137	38.8	410	2.8
C		Zeidler Mills	55°33'	114°50'	670	1.2	-15.5	-1765	15.4	1210	30.9	551	2.2
D		Sexsmith	55°31'	118°30'	805	1.2	-14.9	-1733	15.1	1199	30.0	509	2.4
E		Swartz Creek	53°23'	116°30'	990	2.0	-11.6	-1380	14.5	1123	26.1	580	1.9
F		Prairie Creek	52°15'	115°21'	1220	1.6	-11.7	-1376	13.5	965	25.2	625	1.5
G		Chinchaga	57°50'	118°12'	470	-0.8	-20.8	-2396	15.7	1188	36.5	448	2.7
H		Calling Lake	55°17'	113°09'	625	0.9	-17.5	-1901	15.9	1254	33.4	488	2.6
J		Hanginstone	56°23'	111°26'	540	0.2	-18.8	-2112	16.1	1251	34.8	534	2.3

MAT –mean annual temperature; TCM –mean temperature for coldest month; TWM –mean temperature for the warmest month; NDD degree days below 5°C; GDD –degree days above 5°C; CI –continentality index (TWM *minus* TCM); MAP –mean annual precipitation, AMI – annual moisture index (GDD ÷ MAP); LAT-latitude; LON –longitude; ELE –elevation + -populations planted on all sites.

Appendix III CPP Region G2 Orchard Seed Production and Landscape Deployment Plan (FGRMS Appendix 21A)

1	2	3	4		5	6	7
Tenure Holder (including unallocated area)	**Total Breeding Region/Deployment Zone Area by Tenure Holder**	**Operable Area Within Region/Zone by Tenure Holder**	**Area of Target Strata by Species and Tenure Holder***	**Trees/ha**	**Estimated Plants Required for 100% Planting of Area of Target Strata**	**Planned Total Production Limit, one or more Production facilities (cumulative Ne<30)**	**Planned Total Production Limit, one or more Production facilities (cumulative Ne≥30)**
MDFP	536,557	291,542	194,745	1,160	225,904,200	56,476,050	112,952,100
Non FMA	423,968	199,258	93,955	1,000	93,955,000	23,488,750	46,977,500
FMU P8 (no harvest zone)	284,170	136,188	42,505	0	0	0	0
Non Co-op Member	610,374	369,998	114,032	1,000	114,032,000	28,508,000	57,016,000
Tolko	212,555	138,942	77,666	1,400	108,732,400	27,183,100	54,366,200
	2,067,624	**1,135,928**	**522,903**		**542,623,600**	**135,655,900**	**271,311,800**

*Target strata refers to the area to be regenerated to the species produced by the production facility, not yield strata

Appendix IV Breeding Region G2 Base Population Geographic Origins and Description of Parent Trees

	Breeding Region	Clone #	File Report #	Seed Acc. #	Latitude ⁰N	Longitude ⁰W	Elev (M)	Type of Selection	Breeding Value[1]	% height Superiority	2006 G318[2]
1	G1	X0110	19802	2049	55°38'00"	119°44'00"	855	Comparison	2	47	**8**
2	G1	X0115	19802	2054	55°35'00"	119°32'00"	885	Comparison	2	17.7	**8**
3	G1	X0121	19802	1927	55°24'00"	119°29'00"	520	Comparison	2	16.4	**7**
4	G1	X0122	19802	1926	56°24'00"	119°29'00"	520	Comparison	0	-8.1	**8**
5	G1	X0124	19802	1934	56°16'00"	119°16'00"	425	Comparison	0	-11.3	**10**
6	G1	X0125	19802	1936	56°15'00"	119°02'00"	400	Comparison	2	5.1	**10**
7	G1	X0129	19802	2342	54°31'00"	118°42'00"	885	Comparison	2	8.3	**8**
8	G1	X0138	19802	2345*	54°37'00"	118°37'00"	825	Comparison	0	-5.1	**9**
9	G1	X0152	19812	2452	55°34'00"	119°22'00"	880	Comparison	2	10.6	**0**
10	G1	X0157	19811	2454	55°38'30"	119°41'00"	850	Comparison	2	37.9	**8**
11	G1	X0166	19811	2460	55°41'00"	119°22'00"	850	Comparison	2	22.1	**8**
12	G1	X0193	19812	2355	55°33'00"	119°52'00"	823	Comparison	0	-2.2	**7**
13	G1	X0194	19812	2356*	55°34'00"	119°53'00"	823	Comparison	2	10	**8**
14	G1	X0198	19812	2476	55°29'00"	119°35'00"	854	Comparison	2	3.1	**12**
15	G1	X0199	19812	2477	55°35'00"	119°56'00"	793	Comparison	0	-2.8	**10**
16	G1	X0200	19812	2357	55°35'00"	119°55'00"	854	Comparison	2	7.8	**6**
17	G1	X0202	19812	2479	55°36'00"	119°47'00"	762	Comparison	2	29.8	**8**
18	H	X0356	19864	3048	58°20'00"	118°56'20"	500	Comparison	2	21.9	**8**
19	H	X0482	19874	n/a*	58°14'51"	118°09'13"	518	Comparison	2	5.1	**9**
20	RC	X0683	19901	n/a*	56°31'00"	116°02'00"	610	Comparison	2	18.4	**8**
21	G2	X1226	96-06	4331	57°01'35"	117°58'07"	735	Comparison	2	3	**10**
22	G2	X1227	96-06	4242	57°01'48"	117°58'07"	755	Comparison	2	6	**10**
23	G2	X1228	96-06	4247	56°58'19"	117°52'29"	644	Comparison	2	13.8	**6**
24	G2	X1230	96-06	4334	57°13'08"	118°15'12"	741	Comparison	2	15.2	**8**
25	G2	X1231	96-06	4248	57°05'57"	118°19'29"	851	Comparison	2	7.5	**0**
26	G2	X1232	96-06	4338	57°02'54"	118°15'03"	798	Comparison	2	24.1	**8**
27	G2	X1233	96-06	4332	57°13'08"	118°15'12"	756	Comparison	0	-2	**4**
28	G2	X1234	96-06	4340	57°08'08"	118°20'17"	795	Comparison	2	0.1	**5**
29	G2	X1235	96-06	4243	57°07'15"	118°06'11"	678	Comparison	2	2	**6**
30	G2	X1236	96-06	4244	57°07'15"	118°03'23"	702	Comparison	0	-0.6	**6**
31	G2	X1237	96-06	3979	57°16'12"	118°33'04"	840	Comparison	2	19.6	**5**
32	G2	X1238	96-06	4337	57°20'59"	118°28'12"	814	Comparison	2	6.3	**8**
33	G2	X1278	96-06	5667*	57°03'59"	118°14'39"	794	Comparison	2	6.9	**10**
34	G2	X1279	96-06	4339	57°19'54"	119°03'08"	720	Comparison	2	10.1	**12**
35	G2	X1280	96-06	4333	57°22'18"	118°21'18"	814	Comparison	2	9.3	**11**
36	G2	X1281	96-06	4335	57°23'11"	118°20'28"	823	Comparison	2	13.9	**6**
37	G2	X1282	96-06	4336	57°14'27"	118°16'49"	759	Comparison	2	26.6	**11**
38	G2	X1283	96-06	3980	57°04'25"	117°55'18"	681	Comparison	2	15.2	**12**
39	G2	X1284	96-06	4342	57°19'41"	119°01'30"	751	Comparison	2	3.5	**12**
40	G2	X1285	96-06	4341	57°23'50"	118°55'49"	810	Comparison	2	0.7	**9**
41	G2	X1326	96-06	3981	57°38'41"	117°25'46"	778	Comparison	2	2.9	**11**
42	G2	X1327	96-06	3982	57°37'22"	117°26'35"	676	Comparison	2	8	**6**
43	G2	X1328	96-06	4343	57°22'05"	118°59'53"	659	Comparison	2	2.7	**8**
44	G2	X1329	96-06	4352	57°10'06"	118°33'09"	903	Comparison	2	11.6	**9**
45	G2	X1390	96-06	n/a*	57°36'56"	117°29'52"	548	Comparison	2	13.4	**7**
46	G2	X1391	96-06	4245	57°21'52"	118°39'58"	931	Comparison	0	-3.1	**0**
47	RC	X1392	97-11	n/a*	54°37'00"	118°37'00"	825	Plantation			**3**
48	RC	X1393	97-11	n/a*	55°34'00"	119°53'00"	823	Plantation			**2**
49	RC	X1394	97-11	n/a*	55°34'00"	119°22'00"	880	Plantation			**7**
50	RC	X1395	97-11	n/a*	55°35'00"	119°56'00"	793	Plantation			**3**

	Breeding Region	Clone #	File Report #	Seed Acc. #	Latitude ⁰N	Longitude ⁰W	Elev (M)	Type of Selection	Breeding Value[1]	% height Superiority	2006 G318[2]
51	G2	X1534	97-18	n/a*	57°36'00"	117°31'00"	460	Plantation	0		**7**
52	G2	X1535	97-18	n/a*	55°35'00"	118°18'00"	640	Plantation	0		**8**
53	G2	X1536	97-18	n/a*	56°34'00"	119°40'00"	762	Plantation	0		**8**
54	G2	X1537	97-18	n/a*	54°27'00"	118°38'00"	838	Plantation	0		**5**
55	G2	X1538	97-18	n/a*	55°29'00"	116°05'00"	610	Plantation	0		**6**
56	G2	X1405	98-01	4365	57°04'20"	118°49'48"	760	Comparison	2	18.8	**9**
57	G2	X1406	98-01	4370	57°01'35"	118°49'15"	750	Comparison	2	13.4	**10**
58	G2	X1407	98-01	4354	57°02'54"	118°56'59"	770	Comparison	2	17.9	**6**
59	G2	X1408	98-01	4356	57°03'22"	118°49'40"	755	Comparison	2	7.6	**7**
60	G2	X1409	98-01	4366	56°39'32"	117°58'43"	701	Comparison	2	52.7	**6**
61	G2	X1411	98-01	5668*	57°25'18"	119°14'52"	760	Comparison	2	22.7	**6**
62	G2	X1412	98-01	4249	57°25'18"	119°14'52"	760	Comparison	2	16.4	**2**
63	G2	X1413	98-01	4367	57°00'43"	118°51'13"	846	Comparison	2	0.7	**5**
64	G2	X1423	98-01	4362	56°39'49"	118°00'20"	853	Comparison	2	4.9	**7**
65	G2	X1322	98-02	n/a*	56°27'51"	119°29'16"	533	Comparison	2	8.8	**9**
66	G2	X1323	98-02	4353	56°26'01"	117°57'45"	686	Comparison	2	10	**11**
67	G2	X1324	98-02	4347	56°26'57"	118°03'42"	709	Comparison	2	15.3	**7**
68	G2	X1325	98-02	4348	56°20'24"	118°04'29"	831	Comparison	2	15.2	**6**
69	G2	X1335	98-02	4350	56°26'17"	118°08'50"	686	Comparison	2	14.8	**8**
70	G2	X1336	98-02	4346	56°34'08"	118°45'13"	709	Comparison	2	13.7	**8**
70	G2	X1337	98-02	4349	56°23'37"	117°56'57"	609	Comparison	2	12.2	**6**
72	G2	X1378	98-02	4344	56°37'50"	119°34'40"	716	Comparison	2	20.9	**0**
73	G2	X1379	98-02	4351	56°22'31"	117°58'32"	800	Comparison	2	15.3	**6**
74	G2	X1380	98-02	4345	56°26'04"	118°02'07"	709	Comparison	2	12.2	**10**
75	G2	X1433	98-02	4357	56°45'57"	118°19'39"	732	Comparison	2	41.4	**6**
76	G2	X1434	98-02	4355	56°26'15"	118°25'08"	823	Comparison	2	24.6	**7**
77	G2	X1435	98-02	n/a*	56°45'41"	118°21'31"	792	Comparison	2	17.5	**4**
78	G2	X1436	98-02	4358	56°47'19"	118°25'59"	762	Comparison	2	21	**7**
79	G2	X1437	98-02	4368	56°47'47"	118°26'28"	762	Comparison	2	17	**6**
80	G2	X1445	98-02	4371	56°53'28"	118°35'03"	756	Comparison	2	9.9	**8**
81	G2	X1446	98-02	4374	56°53'21"	118°34'19"	756	Comparison	2	22.2	**3**
82	G2	X1447	98-02	4364	56°37'25"	118°52'57"	999	Comparison	2	19.1	**6**
83	G2	X1448	98-02	4363	56°39'36"	118°33'31"	841	Comparison	2	5.6	**7**
84	G2	X1449	98-02	4373	56°49'50"	118°01'09"	668	Comparison	2	6.7	**5**
85	G2	X1470	98-02	5413*	56°23'43"	117°56'45"	655	Comparison	2	8.1	**12**
86	G2	X1471	98-02	4375	56°24'05"	117°50'01"	820	Comparison	2	10.9	**8**
87	G2	X1472	98-02	4360	56°35'25"	118°24'45"	777	Comparison	2	8.7	**6**
88	G2	X1473	98-02	4359	56°35'26"	118°24'29"	777	Comparison	2	9.1	**11**
89	G2	X1475	98-02	4361	56°24'02"	117°52'45"	808	Comparison	2	3.2	**6**
90	G2	X1476	98-02	4376	56°22'02"	117°56'22"	789	Comparison	2	12.2	**12**
91	G2	X1477	98-02	4372	56°42'19"	118°24'13"	765	Comparison	2	0.9	**12**
92	G2	X1478	98-02	4369	57°25'35"	119°59'57 "	838	Comparison	2	11.2	**7**
93	G2	X1525	98-02	4382	57°26'17"	119°50'32"	792	Comparison	2	8	**10**
94	G2	X1526	98-02	4378	57°52'21"	119°51'54"	777	Comparison	2	0.8	**11**
95	G2	X1527	98-02	4379	56°22'09"	118°04'33"	850	Comparison	2	15.7	**9**
96	G2	X1528	98-02	4381	56°41'37"	118°23'00"	738	Comparison	2	22.6	**11**
97	G2	X1529	98-02	4377	56°57'05"	118°28'36"	628	Comparison	0	-2.2	**9**
98	G2	X1530	98-02	4380	56°58'07"	118°30'26"	634	Comparison	2	13.1	**11**
99	G2	X1531	98-02	5414*	56°35'04"	118°25'56"	777	Comparison	2	9.7	**8**
100	RC	X1490	98-03	4093	57°17'00"	121°40'00"	762	Geographic			**6**
101	RC	X1491	98-03	4094	56°46'00"	121°48'00"	914	Geographic			**9**
102	RC	X1497	98-03	4100	56°56'00"	121°02'00"	853	Geographic			**7**

	Breeding Region	Clone #	File Report #	Seed Acc. #	Latitude °N	Longitude °W	Elev (M)	Type of Selection	Breeding Value[1]	% height Superiority	2006 G318[2]
103	RC	X1498	98-03	4101	56°50'00"	121°30'00"	853	Geographic			**6**
104	RC	X1506	98-03	4109	56°42'00"	121°15'00"	853	Geographic			**7**
105	RC	X1510	98-03	4113	57°15'00"	121°25'00"	756	Geographic			**5**
106	RC	X1516	98-03	4118	56°26'00"	120°23'00"	792	Geographic			**9**

[1] Indicates the %lift in breeding value (Bv) for height that may be used in calculating genetic gain if the tree is a 'Comparison' selection and there is documented height over age superiority.

[2] Indicates the number of ramets or grafts established in the G318 seed orchard in 2006.

* Seedlots (total=2) not included in G352 progeny trials because seed was unavailable; these parents will be tested in new trials once seed collections are completed from parent trees or seed orchard grafts.