Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada

Project A644

Final report to the
Climate Change Impacts and Adaptation Directorate

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1.0 Principal Investigators

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2.0 Summary

Climate change is already signficantly affecting the health and productivity of Canada's forests. Planted forests that are adapted to today's climate will be maladapted when they are harvested in 60-80 years. However, if seedlots for reforestation are selected so as to maximize their adaptation over the duration of their rotation, productivity of Canada's forests could be enhanced by capitalizing on increased future temperatures.

To ensure that the most economically important tree crop planted in Canada - interior spruce (white and engelmann spruce and their hybrids) - is adapted to future climates, forest scientists from western North America have initiated a long-term project that will act as a cornerstone to the genetic resource management of interior spruce in western North America, and as a model for other species and regions.

Wild and domesticated interior spruce seedlots from 128 locations encompassing the climatic and latitudinal range of interior spruce in western North America have been carefully selected, grown, and planted in genetic tests in 18 disparate environments in BC, Alberta and the Yukon. The identity of each of the 73 728 trees planted in the tests has been mapped and recorded, and the test sites will be carefully maintained each year. Researchers will return to gather data on the growth, health and form of the trees, beginning at age 5. The data will be used to describe geographic and climatic tolerances of each seedlot, and to develop a seed deployment strategy that will maximize the health and economic value of interior spruce plantations in future climates.

'Key' funding to initiate this critical project, among the largest in North America, was provided by the Climate Change Impacts and Adaptation Directorate. The project brought together for the first time, four agencies (Research Branch of the British Columbia Ministry of Forests, Alberta Forest Service, Yukon Department of Energy, Mines and Resources, and the USDA Forest Service) in an innovative project that will capitalize on advances in climate modelling, geographic information systems and ecological modelling to provide tools that will help maintain the health and productivity of Canada's forests in a changing climate.

3.0 Background

Interior spruce (white and Engelmann spruce and their hybrids) is widely distributed as the dominant conifer species in western North America. It has significant ecological value and is the most important commercial species of any conifer in Canada. Its growth, form and health, however, are dependent on each seed source (= provenance or population) being planted only in those climates where it is adapted. Climate change is already signficantly affecting the health and productivity of Canada's forests (Logan and Powell2001; Woods et al. 2005; Filmon 2004). Forest productivity modeling predicts large economic losses due to climate change unless changes are made to current seed deployment schemes (Rehfeldt et al. 1999; Rehfeldt et al. 2001).

In genetic tests, seed from various environments (sources) are grown in disparate new environments (test sites) to understand the extent of genetic-by-environment interaction. Such tests serve as *de facto* climate change studies (Carter 1996). Despite extensive genetic testing of interior spruce, the limited environmental range of both seed sources and test sites in current genetic tests unfortunately precludes their use in climate change studies. In addition, few US seed sources have been tested in Canada, although Canadian forest managers will likely become increasingly dependent upon US seed sources as Canada's climate becomes more like that of the northern US.

4.0 Objectives

The main purpose of this project, therefore, is to ensure that western Canada's planted spruce forests are adapted to future climates. Specifically, this project seeks to: 1) understand the distribution of natural genetic variation in interior spruce and 2) to assess the performance of genetically improved spruce populations in disparate environments. This information will help us refine seed transfer guidelines for reforestation and improve conservation strategies for both natural and improved populations for the present climate, and will help us develop seed deployment strategies to maximize productivity and health of forest plantations in future climates.

5.0 Activities

5.1 Seedlots procured

The objective of the seedlot procurement step was to obtain both wild and genetically improved spruce seed from a climatically-diverse a range in western North America. Seed was therefore requested from a wide range of sources, including the BC, AB, YK, and ON governments, private seed owners in BC, and the USDA Forest Service. Of the seed received, a total of 128 seedlots were selected in the following categories:

Elite (A class) seedlots	
BC A class lots	14 seedlots
BC A+ (elite families) lots	13 seedlots
ON A+ (elite families) lots	1 seedlot
AB A class lots	8 seedlots
Wildstand (B class) seedlots	
BC lots	34 seedlots
AB lots	23 seedlots
NWT lots	2 seedlots
YK lots	8 seedlots
Western USA lots	25 seedlots

5.2 Seedlings produced

770 seedlings of each of the 128 seedlots (i.e., 98 560 seedlings) were grown at a commercial seedling nursery in Vernon using standard conifer seedling production techniques. Seed was sown in February 2004 into 415B styroblocks and placed in greenhouses. Seedlots with poor germination (< 95%) were double sown and thinned. All seedlots received identical black-out treatment in August/September. Seedlings were lifted (moved from the greenhouse to cold

storage freezers) in December 2004. The sowing process required approximately 30 person-days of labour, and the lifting process, involving labelling, sorting, bagging and boxing the seedlings for cold storage, required approximately 70 person-days of labour. Use of an incomplete block design considerably increased the labour required for lifting the seedlings, but will improve statistical resolution among the seedlots.

5.3 Test sites identified

Test sites were carefully chosen to uniformly sample the mean annual temperature (MAT), mean annual precipitation (MAP), and latitudinal space occupied by spruce in BC, AB and YK. Candidate regions were identified by filtering an Excel database of 450 Environment Canada meteorological stations on latitude, MAT and MAP. Once 18 regions were finalized, staff worked with industrial and government contacts to identify several candidate sites within each region. Each candidate site was visited to assess its adequacy in meeting the strict test site criteria, and one final site was selected for each region.

Final test sites are located from central Yukon (Mayo) to southern BC (Cranbrook). Geographic coordinates and values of current climate parameters of the 18 test sites are shown in Appendix 2.

5.4 Seedlings planted

Where necessary, test sites were site-prepped and brushed prior to planting. All 18 sites were planted between February and June 2005. The experimental design consists of an incomplete block design containing 8 reps and 16 blocks within each rep. Families were assigned to blocks using the Alphagen software. Seedlots are planted in 4-tree row plots. Spacing is 2 x 1 m to facilitate systematic thinning upon crown closure, and a single row of buffer trees is planted around the perimeter of each test.

5.5 Seed and site climate data obtained

Geographic coordinates and elevation of the 128 seedlots and 18 sites were obtained and entered into the recently released climate interpolation software “ClimateBC” to obtain values of current and future climate variables relevant to seedling growth and health. (See Appendices 1 and 2)

5.6 Information archived

In order to ensure that staff and contractors are able to re-locate the test sites, access notes, GPS coordinates and a series of maps, including aerial photographs, have been prepared for each test site and are stored in hardcopy and electronically. In addition, to facilitate measurement of each tree, layout maps indicating the seedlot to which each planted seedling belongs has been prepared (hardcopy and electronic versions) and the data entered into a hand-held datalogger.

6.0 Activities planned

6.1 Test site maintenance

Each of the 18 test sites will be visited (annually for the first 3 years and every 3 years thereafter) to assess the need for road maintenance, re-labelling of trees, fencing, and vegetation control, and these activities will be performed where needed. Letters will be written to each of the licensees, excluding test sites from their management responsibilities.

6.2 Data collection and analysis

Data related to growth, insect and disease damage, and stem form will be collected every five years, beginning at age 5. A log grade algorithm will be developed utilizing the collected data, and the dollar value of each tree at rotation will be estimated. Average tree dollar values for each seedlot will be calculated at each site and related to test site climate. Relationships of each seedlot’s dollar value with test site climate will enable the most economically productive seedlot to be identified for any planting site considering its projected climate.

6.3 Extension

A fine scale adaptive map of interior spruce in western North America will be developed and distributed to websites frequented by silviculturalists in western North America to help provide an understanding of the patterns of adaptive variation in the species. This map will form the foundation of a review of interior spruce breeding and conservation plans and the development of software that will calculate the impacts of interior spruce seed transfer.

A site-specific, climate-based strategy for deployment of wild and domesticated interior spruce seed will be developed.

The climatic and geographic tolerances of each seedlot will be described in extension notes for foresters and in referreed international publications

7.0 Scientific attention

Although the project is in the early stages, it has gained considerable attention, having been the subject of discussion at various events, including:

- BC Forest Genetics Council's Interior Tree Advisory Committee meeting (Vernon, November 2004)
- Climate change workshops co-hosted by CCAIRN and the McGregor Model Forest (Prince George, November 2004)
- Climate change workshop co-hosted by CCAIRN and UBC (UBC, December 2004)
- International conference on Climate Change and Forest Genetics (http://www.for.gov.bc.ca/hti/ctia/index.htm) (Kelowna, July 2004).
- Alberta Forest Genetics special climate change meeting (Edmonton, April 2005)
- BC MoF – Future Forests Conference (Prince George, December 2005)

8.0 In-kind contributions

128 seedlots were obtained from a range of sources. The cost of field collection of a seedlot varies greatly with geography and proximity to helicopter facilities, ranging from $1000 to $4000 per seedlot.

Sowing and lifting of the seedlings (not included in the seedling production cost) involved approximately 30 and 70 person-days of labour, respectively, and were paid for by the BC Ministry of Forests.

54 boxes of surround (buffer) seedlings were donated by the MoF, at a cost of approximately $50/box.

Project collaborators are listed below. Contributions are described in terms of annual full-time equivalents (FTE) each individual worked on the project between April 2003 and March 2006:

Barry Jaquish (BC MoF scientist)	0.15 FTE
Greg O'Neill (BC MoF scientist)	0.15 FTE
Alvin Yanchuk (BC MoF scientist)	0.05 FTE
Bonnie Hooge (BC MoF technician)	0.40 FTE
Gisele Phillips (BC MoF technician)	0.10 FTE
Val Ashley (BC MoF technician)	0.10 FTE
Jill Peterson (BC MoF administrator)	0.025 FTE
Don White (YK EMR forester)	0.025 FTE
Leonard Bernhardt (AB FS scientist)	0.025 FTE
Jerry Rehfeldt (USDA FS scientist)	0.025 FTE

Maintenance costs of the test sites over the next 10 years are estimated at $90 000. Tree measurement and assessments will be made at ages 5 and 10, and will cost approximately $72 000 on each occasion. These costs will be paid by BC MoF, Alberta Forest Service, and the Yukon Department of Energy Mines and Resources.

9.0 Appendices

Appendix 1 – List of test sites
Appendix 3 – Selected project photographs

10.0 References

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Discussion paper

Seed Transfer and Climate Change

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1.0 Background

This manuscript was developed to promote and facilitate a discussion among forest tree seed users and other stakeholders about the implications and opportunities for changes to seed transfer systems that are being sought to mitigate climate change impacts to forest plantations. The final version of this paper also forms a deliverable for the CCIAD-sponsored project A644: "Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada".

2.0 Seed transfer

Identifying the species and seedlots that are best adapted to a reforestation site is crucial to reforestation successs (Zobel and Talbert 1984). However, in many areas of the province, climate change will render species and seedlots that are adapted today, maladapted toward the end of their rotation, resulting in decreased pest resistance, growth and wood quality. Planting species and seedlots adapted to a longer portion of their rotation (i.e., facilitated migration) is recognized as a cornerstone strategy to mitigate negative impacts associated with climate change (Ledig and Kitzmiller 1992; Schmidtling 1994; Carter 1996; Rehfeldt et al. 1999; Rehfeldt et al. 2001; Rehfeldt et al. 2003; Rehfeldt 2004; Sonesson 2004; Andalo et al. 2005), and in some cases may enhance a site's productivity in a warmer climate (Rehfeldt et al. 2001; Wang et al. 2006).

2.1 Two approaches to seed transfer

2.1.1 Genetic similarity

One approach to regulating seed transfer involves calculating 'genetic similarity' among populations. The procedure uses within- and among-population variation, together with information on local clines (rates of change of genetic differences among populations) from genetic tests to calculate the minimum geographic or climatic distance between populations that are detectably different (Rehfeldt 1988), that is, the distance that results in a maximum acceptable level of genetic dissimilarity (e.g., for many species ~300 m of elevation or 1.5^o C mean annual temperature) (Campbell 1986). Assuming that populations are adapted to their local environments, limiting transfer to locations where genetically similar populations are located ensures that planted trees will be adapted to their new environment. *The procedure has limited ability to estimate transfer impacts because it emphasizes population differences and not seed transfer.*

2.1.2 Transfer functions

A second approach to devising seed transfer distance guidelines involves plotting mean population responses from genetic tests as 'transfer functions' (Raymond and Lindgren 1990). Tree traits of economic interest (e.g., diameter, volume or volume/ha) are used as the response variable, while the geographic or climatic distance that seed is moved (i.e., the elevation, latitude, longitude, or climate value of the planting site minus that of the seed source) is plotted as the independent variable on the X-axis (Schmidtling 1994; Carter 1996; O'Neill et al. 2003). The yield of each provenance can be expressed as a percentage of the expected yield of the local provenance, so that a transfer distance of zero (use of local seed) results in 100% yield.

The transfer function approach identifies environments possessing seed that will perform well at a planting site - sometimes better than local seed (Namkoong 1969). Importantly, it also provides an indication of the rate at which the response trait declines with transfer distance. The typical hyperbolic shape of transfer curves indicates that yield declines exponentially as the seed source departs from a climatic or geographic optima. Transfer curves differ with planting site location and species. *The transfer function approach emphasizes maximizing average population productivity responses to seed transfer across a range of environments.* It does not ensure seed is transferred to genetically or geographically similar areas, and is therefore less conservative than the genetic similarity approach.

2.2 The 'optimum' seed source

The optimum seed source in terms of producing the greatest yield and survival for a given planting site is often a non-local seed source (Namkoong 1969; Rehfeldt et al. 1999; Hamann et al. 2000; Wu and Ying 2004). The optimum source varies with species and planting environment, and can only be determined from the transfer function approach.

In most planting environments the optimum source will be found in moderately warmer (or lower elevation) environments. However, in some warm (or low elevation) planting environments, the optimum source may be found in slightly cooler environments (O'Neill, unpublished data). The latter observation is supported by the finding that provenances of *Abies balsamea* and *Franxinus americana* from eastern North America and *Pinus contorta* var. *contorta* from coastal British Columbia, grew best at sites cooler than their original locations (Roberds et al. 1990; Carter 1996; Rehfeldt et al. 1999).

2.3 Generalists *versus* specialists

The rate at which productivity declines with transfer distance varies by species. The terms ‘generalist’ and ‘specialist’ were coined to describe species that are tolerant and intolerant, respectively, of seed transfer (Rehfeldt 1994b). Data from BC and US provenance tests suggests that Douglas-fir and lodgepole pine (Rehfeldt 1988) are specialists, while western larch, western white pine and western red-cedar are typically considered generalists. Ponderosa pine is intermediate in its response to environmental change (Rehfeldt 1994a). While Interior spruce is intermediate in its tolerance to seed transfer in Utah, Montana and Idaho (Rehfeldt 1994a), it is more of a specialist in BC (Xie et al. 1998).

2.4 Volume, value and uncertainty

Maladaptation can cause impacts beyond mere loss of volume: poor stem form, large branches, and low wood density are associated with some seed transfers (O'Neill et al. 2003). Sparcity of data relating seed transfer to ‘non-volume’ impacts, and the absence of a clear method to translate non-volume impacts to economic impacts currently precludes consideration of non-volume impacts in seed transfer and in many other aspects of silviculture research.

Additional uncertainty is introduced into the estimation of transfer guidelines when dealing with data from young tests. Trees from young tests may not have been subjected to sufficiently extreme weather events to adequately sample temporal variation at each site. Lack of thorough sampling of populations or test environments in genetic tests, or the use of data from tests not designed to furnish seed transfer information can also introduce uncertainty into the estimation of transfer guidelines.

2.5 Pattern and process

Pattern-recognition and process-seeking are fundamental to advancement of natural sciences in general and natural resource management in particular. In the example of the development of seed transfer guidelines, tree breeders seek to observe and establish the pattern of a natural phenomenon (e.g., relationships between survival and climatic transfer distance) {Ying, 2006 #1131}. They then test its causative process and quantify it with predictive models (Watt 1947; Levin 1992), such as transfer or response functions {O'Neill, 2006 #1137}{Carter, 1996 #530}. Predictive models based on a thorough understanding of the processes that drive the pattern (i.e., the forces of natural selection – generally climate variables) are generally most robust and reliable, and underscore the considerable effort in testing, data collection and careful analysis, as seen for example in the CCIAD-sponsored project A644: “Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada”.

2.6 Provenance testing

Provenance testing provides the raw material for constructing operational seed transfer guidelines. The first provenance research was pioneered by Turesson (Turesson 1922), who sought to identify patterns and processes in plant adaptation (Morgenstern 1996). In provenance testing, provenances are sampled across a wide portion of the species' range, and tests are established in replicated and randomized field tests in natural or semi-natural conditions. Test sites are typically distributed across wide climatic or geographic gradients. Provenance responses are correlated to climate variables of the test sites or their surrogates in latitude, longitude and elevation. A significant correlation suggests a causative process of natural selection across the environmental gradient.

3.0 Current seed transfer in B.C.

Seed transfer guidelines in BC were developed largely using 'genetic similarity'-based seed transfer distances, while factoring in operational realities, non-volume factors, concerns regarding risks associated with using data from tests possessing sub-optimal sampling and design or juvenile trees. The current set of seed transfer guidelines therefore represent the boundaries where both adaptability and increased growth potential are accommodated as best as possible, while considering uncertainty and operational realities for each species. *While transfer functions may indicate that acceptable performance is achievable with seed from locations outside current transfer distances, more conservative guidelines have been recommended in some cases in consideration of the issues mentioned above.*

Seed transfer distances will ultimately be best expressed in terms of climatic variables that affect adaptation (Parker and van Niejenhuis 1996; O'Neill et al. 2002). However, for operational simplicity, and in the absence of reliable, fine-scale climate grids, geographic surrogates (elevation, latitude, and longitude) have been employed in B.C. (Ying and Liang 1994; BC Ministry of Forests 1995; Ying and Yanchuk 2006). Elevation is typically the most influential geographic variable in mountainous topography (Roche 1969; Ying et al. 1989; Rehfeldt 1994a) and is the focus of estimating seed transfer impacts below.

4.0 Future seed transfer in B.C.

Transfer distances are currently expressed in geographic distances (latitude, longitude and elevation) for a number of reasons. When sufficient data is available, and an implementation mechanism is feasible, Research Branch may be able to recommend moving to a 'climate based transfer', as this approach will better reflect the environmental factors that populations are actually 'tracking', and will better accommodate climate change scenarios. However, there will be several administrative challenges, primarily modification of the Seed and Planning Registry, before such as system could be developed and implemented.

Heightened calls for facilitated migration and increased species diversity associated with climate change and replanting beetle-infested areas are creating a demand for Class A seed outside of each seedlot's tested environment. Testing of species outside of their current range shows that populations of some species perform remarkably well where they are not currently native, as evidenced by multi-species testing in the Bulkley Valley (Barry Jaquish, pers. comm.). Without better understanding of their productivity, wood quality, and health responses across a wider climatic and latitudinal range, it is difficult to predict which species or breeding populations will be most suitable under future climate projections, particularly if long-distance migration of seed is required.

New canadidate seed transfer systems for BC should be examined from the perspective of ease of implementation, ease of administration, degree to which maladaptation is minimized, degree to which seed transfer opportunities are maximized, and cost. The ideal system will be climate-based, productivity focused, easy to administer and implement, and will easily accommodate the faciliation of seed migration as needed to address climate change.

In summary, seed transfer guidelines will evolve as information from genetic tests becomes available, as climate variables replace geographic variables in population modelling, and as the impact of climate change on forest populations is better understoodApproximately 50 % of all seed planted in the province originates from seed orchards (i.e., Class A seed). By 2013, 75% of planted seed is expected to be Class A seed. (See Business Plan of the Forest Genetics Council of BC http://www.fgcouncil.bc.ca/). The majority of the progeny tests used to evaluate orchard parent trees were established when climate change was not perceived as a significant issue, and the need to move seed large geographic distances to ensure adaptation of planted seed was not envisaged. Consequently, the vast majority of orchard parent trees have been tested only within a narrow climatic and latitudinal range and only within the breeding zone from which they originated (Fig. 1).

5.0 Project Focus

Climate change inserts a new dimension into seedlot selection, because the best adapted seedlots for a site will likely change during the rotation. Identifying the best adapted seedlots will therefore involve maximizing adaptation (the seedlot-climate match) over the course of the rotation. **The CCIAD-sponsored project A644 "Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada" will provide the data required to develop a climate-based, productivity-focused seed transfer system that accomodates facilitated migration. As such, it is a template for the type of tests required in the future to maximize adaptation of Canada's forest plantations.**

The primary focus of the "Seed source selection and deployment to address adaptation to future climates for interior spruce in western Canada" project, therefore, is to develop an understanding of the adaptation of each breeding population, as represented by class A seedlots or seed from elite families, across a range of climatic and latitudinal environments in BC. Knowledge of the adaptive response of each seedlot will form the foundation of a system of facilitated migration of seed that will mitigate maladaptive responses and potentially enhance forest productivity in some areas (Wang et al. 2006), while ensuring that the gains achieved through four decades of tree breeding in BC will be realized in a future climate. Moreover, comparision of this study with future studies of other species may allow inter-specific comparisions, which will also contribute to our understanding of the growth and yield of mixed species planations and future modeling of interspecific competition in naturally regenerated stands.

An extensive set of Class A seedlot tests is required across a diverse array of climatic and latitudinal environments. By relating test site climate and latitude (photoperiod) to productivity of each Class A seedlot (Fig. 3), those species and seedlots that will maximize the productivity, wood quality and health of BC's forests in future climates can be identified, and this information incorporated into species and seedlot selection systems.

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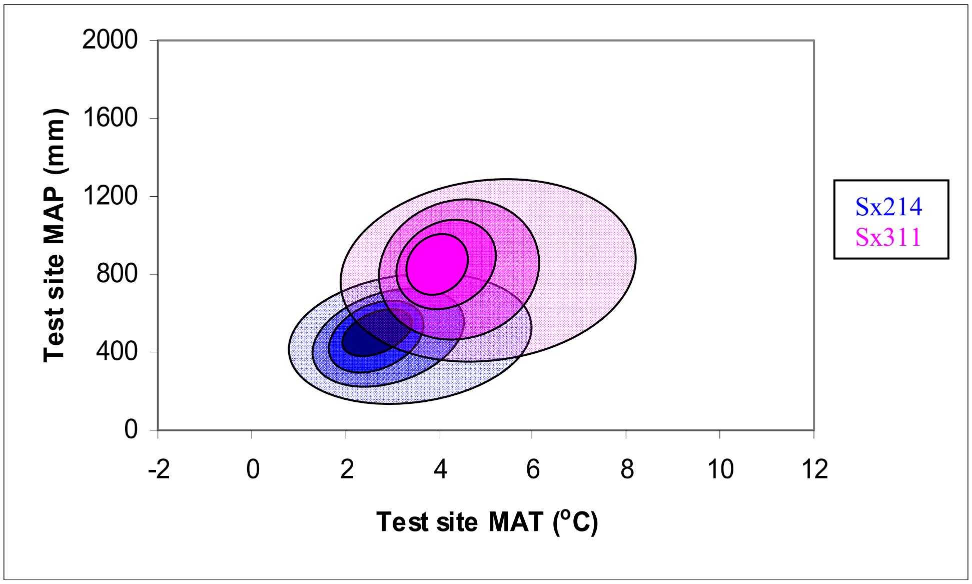

Fig. 1. Example of possible genetic worth clines of two seed orchards based on two climate variables. Knowledge of such GW clines could alter seedlot selection decisions and improve adaptation and productivity of plantations. In addition, GW clines would greatly improve the ability to make informed decisions regarding facilitated migration of species and seedlots.