

**Assisted Migration Adaptation Trial:
Responding to climate change by assisting Class A seedlot migration**

Workplan

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1.0 Summary

In many areas of the British Columbia, seedlots that are adapted today will be rendered maladapted toward the end of their rotation by climate change, resulting in decreased pest resistance, growth and wood quality. Planting seedlots adapted to future climates (i.e., assisted migration) is recognized as an effective, pro-active and inexpensive strategy to mitigate negative impacts associated with climate change, and in some locations may enhance a site's productivity in a warmer climate.

The Assisted Migration Adaptation Trial (AMAT) will test 49 seed sources representing breeding populations in BC and adjacent states across 48 long-term field test sites located between central Yukon and southern Oregon. Twelve tests per year for each of 4 years will be established, beginning in spring 2009. Growth, health and wood quality will be measured every five years. Use of local wildstand control seedlots and block plots will enable estimated genetic gains to be verified for each seedlot at each test site. Productivity of each breeding population will be described as a function of the climate and latitude of the test sites. These response functions will underpin the development of an assisted migration deployment system that will help maximize forest productivity while helping to maintain forest health and wood quality and ensuring the widest deployability of every seedlot.

2.0 Background

Identifying seedlots that are best adapted to a reforestation site can be one of the most important reforestation decisions (Zobel and Talbert 1984). However, in many parts of BC, seedlots that are well-adapted today will be poorly adapted in their last two or three decades, resulting in decreased pest resistance, growth and wood quality. Assisted migration (i.e., planting seedlots adapted to future climates) is recognized by many researchers as a pro-active, effective strategy to mitigate negative impacts associated with climate change (Ledig and Kitzmiller 1992; Schmidting 1994; Carter 1996; Rehfeldt et al. 2001; Rehfeldt 2004; Sonesson 2004; Millar et al. 2007; St Clair and Howe 2007; O'Neill et al. 2008), and in some locations may enhance a site's productivity in a warmer climate (Rehfeldt et al. 2001; Wang et al. 2006a).

Approximately 50% of all seed planted in the province originates from seed orchards (i.e., Class A seed). By 2013, approximately 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/>). However, little is currently known about the adaptive responses of breeding populations of BC's commercially important tree species. 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). To ensure that each reforestation site receives the seedlots that are best adapted and most productive for its current and future climate, each breeding populations must be tested across a broad range of climatic and latitudinal environments.

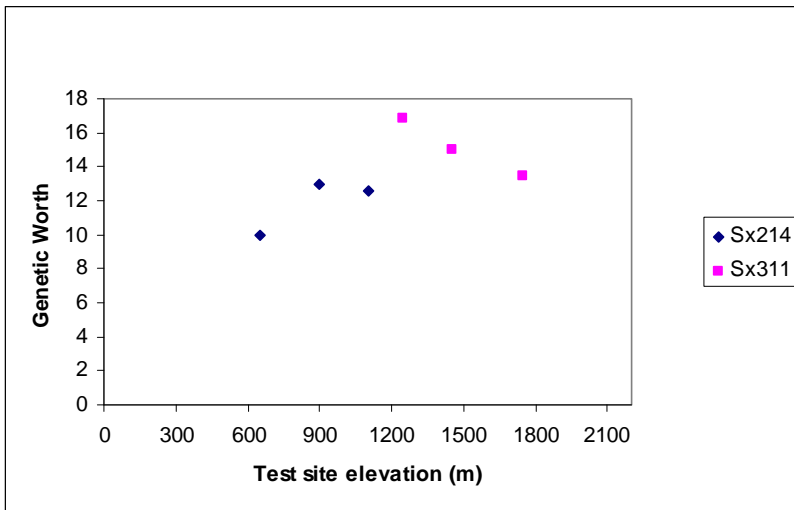


Fig. 1. Fictitious example of genetic worth (expected percent volume gain at rotation) of two seed orchard seedlots each tested at three locations. Response functions describing genetic worth as a function of climate or elevation are difficult to determine from such a limited number and range of tests.

Heightened calls for assisted 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. In addition, 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.) and in the Cariboo (Koot 2007) (see http://www.for.gov.bc.ca/hfd/library/FIA/2007/LBIPI_4638002a.pdf). While wider deployment may be desirable, without better understanding of their productivity, wood quality, and health responses across a wide climatic and latitudinal range, it is difficult to predict which Class A seedlots are most suitable for current or future climates or the level of genetic gain anticipated in each environment (Fig. 2).

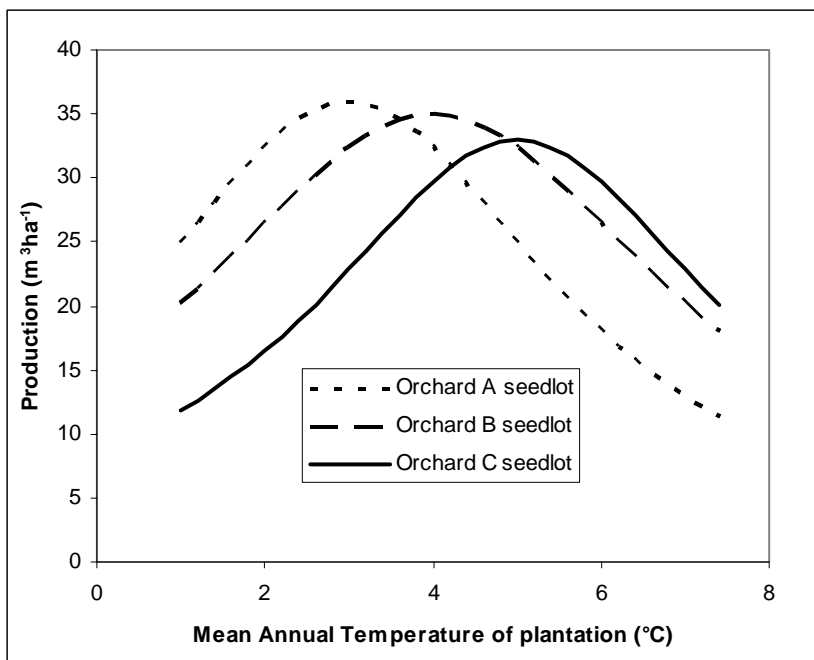


Fig. 2. Schematic illustrating possible response functions of three seed orchard seedlots. Knowledge of response functions such as these could help identify seedlots expected to be best adapted and most productive at each temperature.

3.0 Objectives

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 over the course of the rotation.

The primary objective of this project, therefore, is to develop an understanding of the adaptation of each breeding population, as represented by Class A seedlots, across the range of climatic and latitudinal environments in BC. Field test results will be used to form multi-variable response functions (Wang et al. 2006b) for each seedlot using a range of key climatic variables and photoperiod (latitude) (Fig. 3). The functions will form the foundation of a system of assisted migration of seed that will help mitigate maladaptive responses in some areas, while potentially enhancing forest productivity in other areas (Wang et al. 2006a), and ensure that the gains achieved through four decades of tree breeding in BC will be realized in a future climate.

Second, by testing each seedlot across a wide geographic range, it will be possible to empirically identify areas outside of the current range of each species where it could grow well. Third, wildstand local control seedlots will be planted at each test site, enabling the growth of each seedlot to be compared to that of wildstand seed, and a realized genetic gain to be estimated for each orchard seedlot in any climate. Spatially explicit estimates of realized genetic gains calculated for each seedlot will significantly improve the accuracy of genetic gain contributions to timber supply analyses.

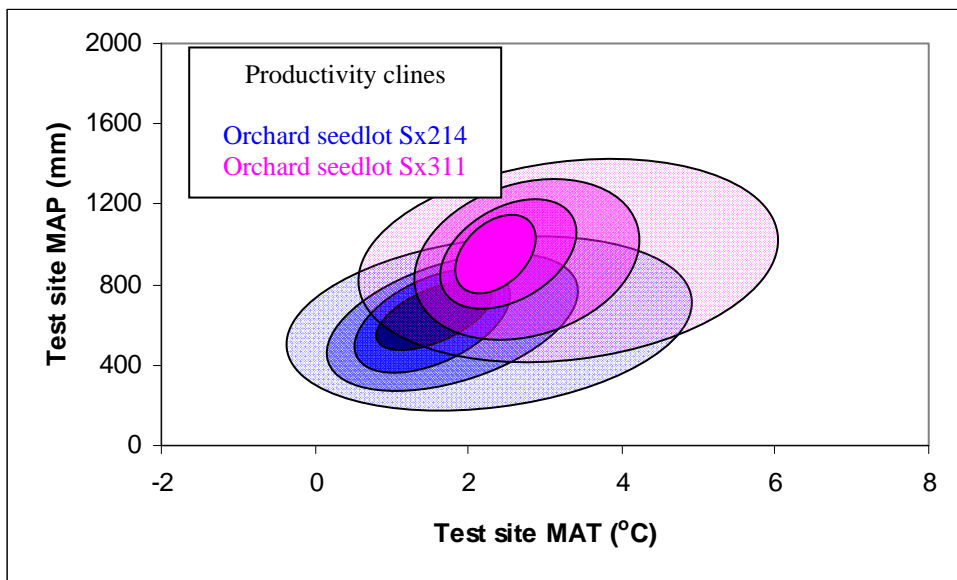


Fig. 3. Example of possible productivity response functions of two seed orchards seedlots based on two climate variables. Knowledge of such response functions will greatly improve the ability to make informed decisions regarding assisted migration of seedlots that will lead to improved productivity of plantations.

The proposed project addresses critical knowledge gaps in our understanding of the growth of genetically improved seedlots across a range of climates and latitudes. 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 to productivity, wood quality and health of each Class A seedlot (Fig. 3), those species and seedlots that will maximize these attributes of BC’s forests across the climates of a future rotation can be identified, and this information incorporated into species and seedlot selection systems, as well as growth and yield and timber supply models.

4.0 Project Design

4.1 Seedlots

Forty-nine experimental seedlots – 40 from BC and 9 from neighbouring states (Washington, Oregon and Idaho and Montana - will be solicited from seed owners. Improved populations from the USA are needed in the project because these could prove to be the best adapted populations for an assisted migration program in the southern interior at the time the trial yields useful data (approximately 2026). At each site, 100 seedlings from each of 32 seedlots (experimental seedlots and local control seedlots) will be planted.

4.2 Sites

To ensure that the test sites span the range of BC’s future climate, BC and neighbouring states have been divided into 48 climate zones using multi-variate analyses of 8 climate variables. One test site will be established in each of the 48 climate zones.

4.3 Design

Preliminary analyses to identify experimental designs that would yield the most accurate rotation-age volume estimates (i.e., by minimizing inter-seedlot competition) while minimizing experimental effort at each site were conducted by growth and yield specialist, Ian Cameron (Azura Consulting) using the Illingworth lodgepole pine provenance dataset. Results of his analyses in TASS (Tree And Stand Simulator) suggest that error increases rapidly with less than 4 replications for plots of 5 x 5 trees (Fig. 4).

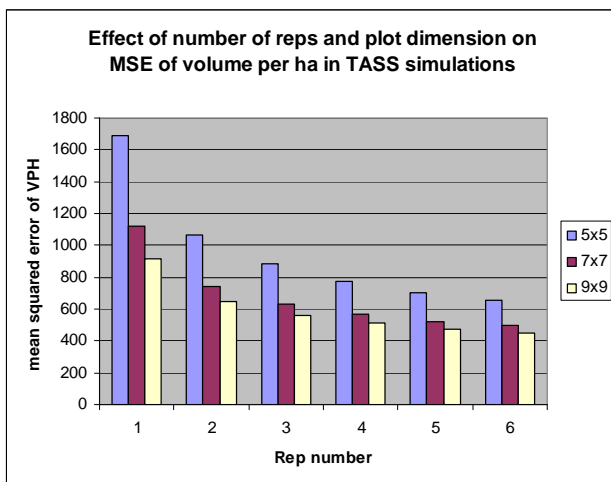


Fig. 4. Mean squared error of vol. per ha for various combinations of rep number and plot dimension.

At each site the 32 experimental seedlots and local control seedlots will be planted in 4 blocks. Within each block, each seedlot will be planted in a **5 x 5 square plot**. Therefore, each site will receive **25 trees/seedlot x 32 seedlots/block x 4 blocks = 3200 trees**. Approximately 300 buffer trees will surround the plantation, for a total of 3500 trees at each site. Spacing will be inversely related to

productivity so that tests arrive at crown closure at the same age. Average spacing will be 2.5 x 2.5 m (6.25 m²/tree), requiring **2.2 ha per site**.

To further reduce inter-seedlot competition, and thereby extend the longevity of the trial and improve the accuracy of growth extrapolations to rotation, a split-plot design will be employed, with the main plot factor comprised of species, and the sub-plot factor comprised of seedlots within species.

4.4 Planting and maintenance

Due to the large number of tests, planting will be done over 4 years (12 test sites/year), beginning in spring 2009. Zonal sites (i.e., broadly mesic and mesotrophic) will be sought for tests so that growth in the tests reflects the influence of the regional climate. Sites will be selected for uniformity to minimize environmental 'noise' and maximize genetic differentiation among seedlots. Mechanical site preparation will be applied as required. Fences will be built where deer browse or cattle trampling is expected. Sites will be visited the first two years after planting to remove competing vegetation and ingress.

4.5 Weather and climate data

Battery-powered Hobo temperature sensors and data loggers capable of sensing hourly temperature and logging 16 months of records will be installed at each site and downloaded annually. Monthly test site precipitation will be interpolated from Environment Canada meteorological records using ANUsplin software, and biologically meaningful climate variables derived from the monthly temperature and precipitation data.

4.6 Measurement and analysis

Height, diameter and survival will be measured and health and wood quality (stem form, branch size) assessed on all trees at 5-year intervals, beginning at age 5. Growth statistics of each seedlot will be input into TASS, and expected volume at rotation estimated for each seedlot at each site. Volume at rotation of each species will also be expressed as a percent of the local control seedlot to calculate realized gain of each seedlot.

Rotation-age volume of each seedlot will be related in multiple regression to the climate of the test sites in which it was planted to develop climate/latitude-based productivity response surfaces (equations). Future climate estimates for each 400 x 400 m cell in BC will be obtained from Climate BC (<http://genetics.forestry.ubc.ca/cfgc/climate-models.html>) for each decade for the period 2026 to 2106. These values will be inserted into the regression equations to estimate the rotation-age volume of each seedlot each decade and averaged over the rotation. In this way, spatially explicit (i.e., across the entire province) estimates of rotation-age volume will be obtained for each tested Class A and B seedlot, and the most productive seedlots of each species identified for each cell.

Maps will then be developed illustrating the productivity of each seedlot and identifying superior seedlots throughout the province. Exclusion of 20% of the test sites from the analysis will serve to verify the accuracy of the model. Health and wood quality concerns will be quantified for each seedlot in each biogeoclimatic variant group. Thresholds of acceptable health and wood quality traits will be selected and unacceptable deployment zones identified for each seedlot. Measurements and analysis will be repeated every 5 years to refine the productivity estimates, maps and the deployment system.

4.7 Implementation

Results of this study will provide the first province-wide, side-by-side, quantitative, empirical evaluation of productivity of Class A seedlots of all commercially important species in BC, and will result in a spatially explicit description of the productivity of selected seedlots from BC and neighbouring states. This information will be central to the development of a provincial climate-based seed transfer system by Tree Improvement Branch of the BC Ministry of Forests and Range. Such a system, potentially based on a set

of fine scale climate maps and a ‘transferability matrix’ of seedlots among zones will help maximize forest productivity, health and wood quality in current and future climates.

Periodic growth data collected in this study will be made available to the Stand Development Modelling group of Research Branch to help incorporate the effects of breeding and selection into their tree and stand simulation and timber supply models.

5.0 Extension

The conceptual development of this initiative began approximately 5 years ago, and its importance as a key component of the province’s climate change strategy is recognized by the proponents and the Future Forest Ecosystems Initiative. Therefore, extension efforts intended to communicate the importance of climate change, adaptation, and seedlot selection in general, and the objectives, design and implementation of this study in particular, began several years ago, and have included presentations to licencees and stakeholder groups such as the Southern Interior Silviculture Committee, the Forest Nursery Association of BC, Canadian Tree Improvement Association, and the Interior Technical Advisory Committee of the Forest Genetics Council of BC. Extensive input and review has been solicited on the project over the last 2 years from the tree breeding and research community.

An article summarizing the objectives, design and implementation of this study has been submitted to TICtalk, a newsletter of the Forest Genetics Council - one of the primary means of communication among BC’s forest genetics community. In addition, the project was discussed recently with a delegation of Oregon and Washington researchers and industrial foresters, and will be presented at a climate change workshop hosted by Forest Genetics Ontario.

Extension of this project will involve continuing to communicate the project rationale, as well as the progress of test site establishment to the tree improvement community via the TICtalk newsletter, regular meetings of the interior and coastal Technical Advisory Committees of the Forest Genetic Council, and to the forestry community via the interior and coastal silviculture committees, and the Research Branch website. (Updates are already planned for the Forest Genetics Council (Nov 2007) and the Southern Interior Silviculture committee (April 2008).)

While the first set of results is approximately 12 years away, close collaboration between Research and Tree Improvement Branch will be required to effectively implement any new seed transfer policies or refinements to the seed deployment system (Seed Planning And Registry, SPAR). Anticipated changes to the deployment system will be communicated as early as possible so as to allow sufficient opportunity for seed growers and users to accommodate the changes. A coordinated communication strategy will be developed via a stakeholder committee of the interior and coastal Technical Advisory Committees of the Forest Genetics Council.

The Illingworth lodgepole pine provenance tests established in 1974 have been the key source of information and material for adaptation studies in BC, resulting in over two dozen research articles that have guided genetic resource management in the province. The proposed project seeks to duplicate the Illingworth study using genetically selected seedlots and local wildstand controls of all commercial species. These trials will provide significant opportunities for theoretical and applied research and publication in several disciplines including forest health, climate change, ecophysiology, growth and yield, and tree improvement. In the area of forest genetics, publications along the the following themes are anticipated:

- Characterizing the adaptation of BC’s commercial tree species

- Assisted migration to mitigate climate change impacts
- Quantifying the impact of breeding and selection on genetic diversity and adaptation of conifers
- A spatially explicit analysis of realized genetic gains in BC's tree improvement program
- Empirical support for species migration

6.0 Performance indicators

Twelve test sites will be planted each year for 4 years. Therefore, each of the indicators will repeat annually for 4 years.

Indicator	Target	Completion Date
Expt'l design review	revised proposal	March 2007
Test sites identified	12 test sites	Nov 2007
Seedlots procured	30 Class A lots and 4 Class B controls/site	Dec 2007
Seedlots sown	30 Class A lots and 4 Class B controls/site	April 2008
Test sites planted	12 test sites	July 2009
Test sites maintained	12 test sites	June 2010

7.0 Costs

Start-up funding to cover costs of some of the initial seed purchase and travel expenses associated with test site selection and extension were provided by the BC Forest Genetics Council for fiscal years 2006/07 and 2007/08. Funding for fiscal years 2008/09 and 2009/10 has been received from the Forest Investment Account – Forest Science Program (FIA/FSP). Fund after 2009/10 is anticipated from (FIA/FSP).

Estimated annual costs for this project are shown to the end of fiscal 2017/2018 (year 10) in Appendix 1. Not shown are the in-kind salaries of 6 BC MoFR staff who are contributing to this project (total = approximately 3 FTEs) to help over-see planning, site reconnaissance, sowing, lifting, layout, planting, site and climate station maintenance, data management, and contract supervision. Also, much of the seed will be obtained *gratis* from BC Timber Sales, corporate donors and our collaborator, the Inland Empire Tree Improvement Coop, at a value of approximately \$15000/y.

8.0 Project Team

Greg O'Neill, BC MFR Research Branch
 Michael Carlson, BC MFR Research Branch
 Vicky Berger, BC MFR Research Branch
 Nicholas Ukrainetz, BC MFR Research Branch

9.0 Collaborators

Marc Rust, Inland Empire Tree Improvement Coop

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Multi-species Class A Adaptation Trial - Budget timeline

Activity	2008/09 Year 1	2009/10 Year 2	2010/11 Year 3	2011/12 Year 4	2012/13 Year 5	2013/14 Year 6	2014/15 Year 7	2015/16 Year 8	2016/17 Year 9	2017/18 Year 10	Total
Seed (years 1-3)	9000	9000	9000								\$27,000
Travel, meal, accom (years 1-3)	10000	12800	12800								\$35,600
Seedlings: (year 1-4) 3200 seedling/site x 12 sites/y x 1.25 over-sow x \$0.30/sdln	14400	14400	14400	14400							\$57,600
Lifting: (years 1-4) 15 p-d/y @ \$300/p-d	4500	4500	4500	4500							\$18,000
Site prep: (years 1-4) 6 sites/y x \$2000/site	12000	12000	12000	12000							\$48,000
Layout and staking: (years 1-4) 4 p-d/site x 12 sites/y x \$400/pd (incl. travel)	19200	19200	19200	19200							\$76,800
Plant, sitemap: (years 2-5) 14 p-d/site/y x 12 sites/y x \$400/p-d (incl travel)		67200	67200	67200	67200						\$268,800
Stakes, flags, labels, pins (years 2-5) \$500/site/y x 12 sites/y		6000	6000	6000	6000						\$24,000
Meteorological station: (years 2-5) \$1100/site x 12 sites/y		13200	13200	13200	13200						\$52,800
Fencing: (years 2-5) 3 sites x \$5000/site		20000	20000	20000	20000						\$80,000
Site maintenance: (years 3-10) 4 p-d/site x 12 sites x \$400/p-d (incl. travel)			19200	19200	38400	38400	19200	19200			\$153,600
Extension, communications (years 1-4)	2000	2000	2000	1000	1000	1000	1000	1000	1000	1000	\$13,000
Sub-total	\$71,100	\$180,300	\$199,500	\$176,700	\$145,800	\$39,400	\$20,200	\$20,200	\$1,000	\$1,000	\$855,200
Delivery allowance (8%)	\$5,688	\$14,424	\$15,960	\$14,136	\$11,664	\$3,152	\$1,616	\$1,616	\$80	\$80	\$68,416
TOTAL	\$76,788	\$194,724	\$215,460	\$190,836	\$157,464	\$42,552	\$21,816	\$21,816	\$1,080	\$1,080	\$923,616

Appendix 1. Timeline and estimated costs of activities associated with Assisted Migration Adaptation Trial.