Assisted Migration Adaptation Trial

Workplan
(Updated January 2011)

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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 48 seed sources representing breeding populations in BC and adjacent States across 48 long-term field test sites located between central Yukon and northern California. 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 adaptation of forest forest plantations, thereby maximizing productivity, forest health and wood quality.

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 and neighbouring States, 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; Schmidtling 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 to ensure adaptation of plantations was not envisaged. Consequently, the vast majority of orchard parent trees has been tested within only 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.

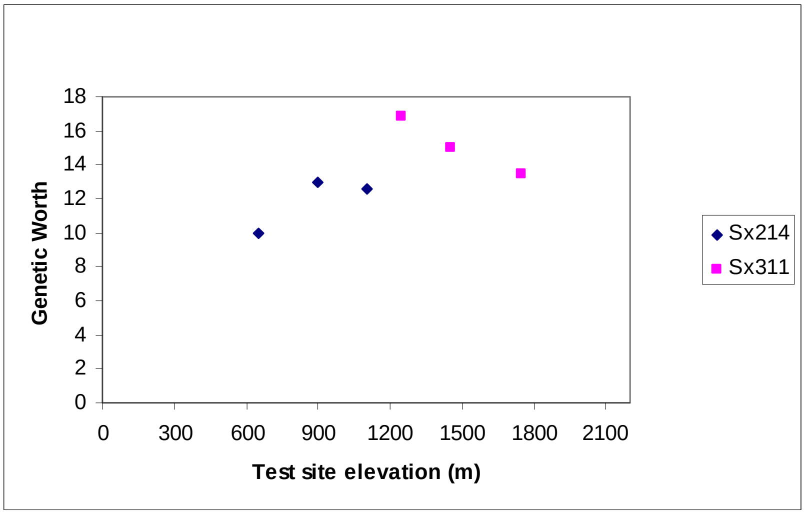

Fig. 1. Schematic example of genetic worth (expected percent volume gain at rotation) of two seed orchard seedlots each tested at three locations. Response functions describing genetic worth as a function of climate or elevation are difficult to determine from such a limited number and range of tests.

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 Region (Koot 2007) (see http://www.for.gov.bc.ca/hfd/library/FIA/2007/LBIPI_4638002a.pdf). While wider deployment may be desireable, 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).

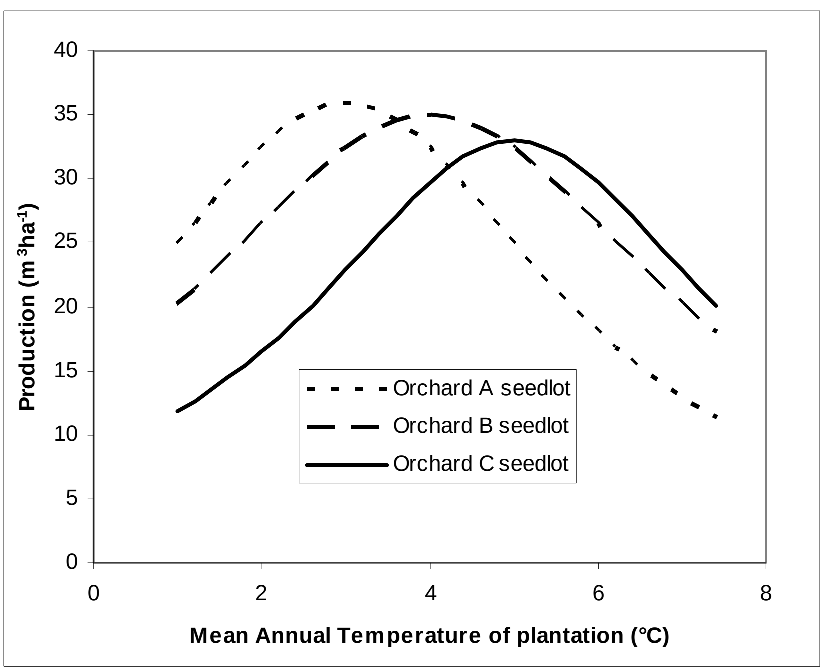

Fig. 2. Schematic illustrating possible response functions of three seed orchard seedlots. Knowledge of response functions such as these could help identify seedlots expected to be best adapted and most productive at each temperature.

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.

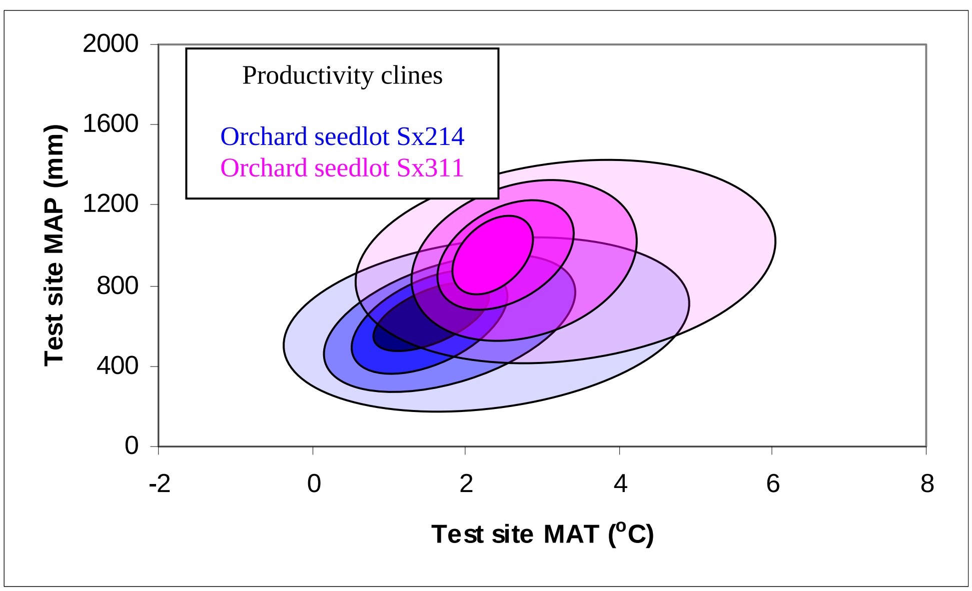

Fig. 3. Example of possible productivity response functions of two seed orchards seedlots based on two climate variables. Knowledge of such response functions will greatly improve the ability to make informed decisions regarding assisted migration of seedlots that will lead to improved productivity of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

Extensive input and review of this project was solicited from the tree breeding, research and seed user community. Continuing input is invited and may be provided to the project team (seed below).

4.0 Project Design

4.1 Seedlots

Forty-eight experimental seedlots from 15 commercial tree species will be tested. Of the 48 seedlots, 39 are from BC and 9 are from neighbouring states (Washington, Oregon, Idaho and Montana. Seedlots are from improved populations and were selected because of the expectation that they will be important seed sources for BC in the future.

Species	SItype	SPZ	Orchard_num	Lat	Long	Elev	MAT	MWMT	MCMT	TD	MAP
At	PseudoA	At_SouthInt	At_SouthInt	49.90	120.63	1050	4.3	15	-6.3	21.3	513
Ba	PseudoA	Ba_SouthInt	Ba_SouthInt	49.65	121.10	1175	4.9	14.9	-4.6	19.5	2215
Bg	PseudoA	Bg_Koot	Bg_Koot	49.45	117.48	850	5.7	16.8	-5.6	22.4	966
Bl	PseudoA	Bl_SouthInt	Bl_SouthInt	50.98	119.70	1524	2.3	13.3	-8.3	21.6	733
Cwrc	Class A	M Low	140	49.83	124.66	229	8.3	16.1	1.7	14.3	2364
Cwri	PseudoA	Cwri_Koot	Cwri_Koot	50.72	118.61	410	4.8	16.1	-7.1	23.2	834
Ep	Class A	southBC	Skim_Kal	50.61	118.67	670	5.4	16.9	-6.7	23.6	705
Fdc	Class A	SM	181	50.36	123.16	558	5.8	15.5	-3.8	19.3	1867
Fdc	Class A	M Low	166	49.22	123.43	409	8.4	16.4	1.3	15.1	2351
Fdc	Class A	CoosBay OR	CoosBay OR	43.39	124.03	238	11.4	17.2	6.2	11.0	1763
Fdc	Class A	Longview WA	Longview WA	46.21	122.72	335	10.0	17.5	2.7	14.8	1893
Fdc	Class A	Springfield OR	Springfield OR	44.03	122.63	447	11.2	18.9	4.7	14.2	1541
Fdi	Class A	PG	225	53.58	122.78	772	3.2	14.5	-9.7	24.2	648
Fdi	Class A	QL	226	52.35	120.92	925	3.2	14.3	-8.9	23.2	681
Fdi	Class A	CT	231	52.74	122.17	853	3.6	14.7	-8.9	23.7	591
Fdi	Class A	NE	321	50.74	118.63	641	5.5	17.0	-6.6	23.6	824
Fdi	Class A	NE	324	50.13	117.71	1086	4.1	15.7	-7.6	23.3	926
Fdi	Class A	ID	Cherry Lane	47.44	116.40	870	6.9	17.9	-3.5	21.4	895
Hwi	PseudoA	Hw_Monashee	Hw_Monashee	50.77	119.10	800	5.2	16.7	-7.0	23.6	867
Hwc	Class A	M Low	133	50.32	125.53	139	8.5	15.8	2.0	13.7	2308
Hwc	Class A	M	196	49.53	123.53	773	6.6	15.0	-0.8	15.8	2575
Lw	Class A	NE Low	332	49.83	117.83	865	4.9	16.5	-6.9	23.4	828
Lw	Class A	EK	333	49.85	115.70	1096	3.7	15.9	-9.1	25.0	640
Lw	Class A	ID	IETIC/USDA	48.36	116.30	1120	5.5	16.9	-5.5	22.4	901
Lw	PseudoA	OR	OchocoNatFor	44.33	120.04	1501	6.9	17.0	-1.1	18.2	754
Pli	Class A	CP	218	54.06	123.40	798	2.7	14.2	-10.3	24.5	645
Pli	Class A	BV	219	53.49	123.51	858	3.0	14.2	-9.4	23.5	662
Pli	Class A	PG Low	222	52.84	121.85	827	3.7	14.9	-8.6	23.5	710
Pli	Class A	TO Low	311	50.53	119.07	952	4.7	16.0	-7.1	23.0	631
Pli	Class A	NE Low	337	50.69	119.16	910	5.1	16.4	-6.7	23.2	670
Pli	PseudoA	Pli_IETIC_MO	Pli_IETIC_MO	47.84	115.64	792	6.1	17.6	-5.4	23.0	960
Pw	Class A	M Low	175	48.15	123.85	660	7.7	15.7	0.7	15.0	1762
Pw	Class A	KQ	335	47.59	116.04	1157	5.9	16.8	-3.9	20.7	1189
Py	Class A	ID	Plains	47.98	115.26	897	7.0	18.6	-4.6	23.3	605
Py	PseudoA	Py_SouthInt	Py_SouthInt	50.28	121.40	560	6.3	17.8	-5.8	23.6	539
Ss	Class A	M All	172	49.45	124.04	65	9.1	16.9	2.1	14.8	1572
Sx	Class A	PG	206	55.01	124.80	942	1.7	13.3	-10.8	24.1	642
Sx	Class A	PG	211	53.88	122.94	834	2.8	14.3	-10.2	24.5	668
Sx	Class A	TO	303	50.23	120.04	965	4.6	15.6	-6.7	22.3	522
Sx	Class A	TO	303	50.21	120.33	1329	3.2	14.0	-7.4	21.4	604
Sx	Class A	EK	304	50.45	115.83	1192	2.6	14.9	-10.5	25.4	766
Sx	Class A	NE Mid	305	50.66	118.42	1160	3.4	14.6	-8.1	22.7	845
Sx	Class A	NE High	306	51.24	119.57	1633	1.3	12.1	-9.5	21.6	1003
Sx	Class A	NE	341	50.51	114.61	524	5.4	17.0	-7.6	24.6	727
Sx	Class A	BV	620	54.33	126.52	792	2.7	13.7	-9.4	23.1	561
Sx	PseudoA	Se_IETIC_MO	Se_IETIC_MO	48.03	115.19	1052	6.1	17.5	-4.9	22.4	718
Ycc	Class A	M All	CLRShedge	49.67	124.26	1000	5.4	14.2	-1.9	16.1	3100
Yci	PseudoA	Yci_Koot	Yci_Koot	49.85	117.70	1700	2.2	13.7	-9.2	22.8	1160

Table 1. AMAT seedlots. Pseudo A seedlots are bulked wildstand collections. See http://www.for.gov.bc.ca/hre/becweb/resources/codes-standards/standards-species.html to obtain species codes. SPZ = seed planning zone. MAT= mean annual temperature; MWMT = mean warm month temperature; MCMT = mean cold month temperature; TD = temperature difference (MWMT-MCMT); MAP = mean annual temperature.

4.2 Sites

To ensure that each seed source is tested in climates warmer, colder, wetter, drier,north and south of its origin, test sites had to span a wide climate range. Therefore, BC and neighbouring states were divided into 48 climate zones using multi-variate analyses that included latitude and 8 climate variables. One test site will be established in each of the 48 climate zones. At each site, 100 seedlings from each of 32 seedlots (experimental seedlots and local control seedlots) will be planted.

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).

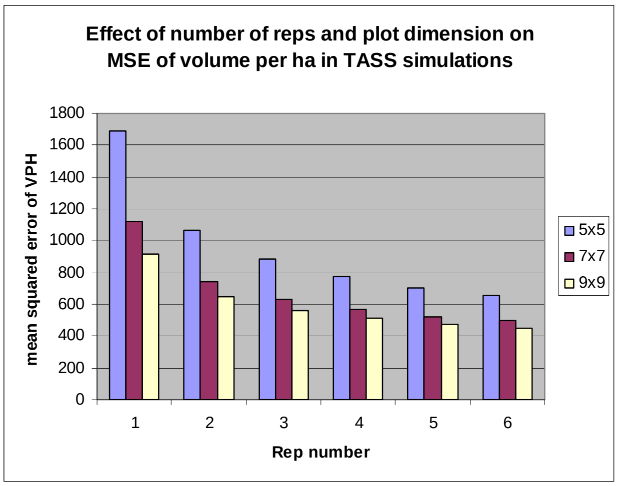

Fig. 4. Mean squared error of vol. per ha for various combinations of rep number and plot dimension.

Therefore, to balance competing needs of providing large plots to minimize inter-plot competition, and maintain test site site at a manageable size, at each site 32 (of 48) experimental seedlots and local control seedlots will be planted in 4 blocks. Within each block, each seedlot will be randomly assigned to a 5 x 5 square plot. Therefore, each site will receive 25 trees/seedlot x 32 seedlots/block x 4 blocks = 3200 trees. Approximately 260 buffer trees will surround the plantation (depending on plantation dimensions). Spacing will be 2.5 x 2.5 m (6.25 m^2/tree), requiring 2.2 ha per site, including buffer trees. Each seedlot will be planted at approximately 30 sites.

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 so that growth 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 or elk browse or cattle trampling is expected. Sites will be visited as required to remove competing vegetation and ingress.

4.5 Weather and climate data

Battery-powered Hobo temperature sensors and data loggers capable of measuring precipitation and sensing hourly temperature will be installed at each site. Loggers will be downloaded annually. Biologically meaningful climate variables will be 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 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 PNW (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 (orchard) and B (wildstand) seedlot, and the most productive seedlots of each species identified for each cell.

Maps will then be devloped 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 refinement of a provincial climate-based seed transfer system operated by the Seed Planning And Registry (SPAR) system of Tree Improvement Branch of the BC Ministry of Forests, Mines and Lands. These refinesments 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 in 2005, and its importance as a key component of the province's climate change strategy is recognized by the proponents, the Future Forest Ecosystems Initiative, and the BC Forest Genetics Council. Therefore, extension efforts intended to communicate the importance of climate change, adaptation, and seedlot selection in general, and the objectives, design and direction of this study in particular, 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, Canadian Forest Genetics Association, the Western Forest Genetics Association and FORREX. Input form these groups will continue to be solicited as the project progresses.

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 applied research in several disciplines including forest health, climate change, ecophysiology, growth and yield, and tree improvement.

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	48 experimental lots and local controls	Dec 2007
Seedlots sown	48 experimental lots and local controls	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:

BC Forest Genetics Council	2006/07	Start-up funding
BC Forest Genetics Council	2007/08	Start-up funding
FIA – Forest Science Program	2008/09	Operating budget
FIA – Forest Science Program	2009/10	Operating budget
Land Base Investment Program	2010/11	Operating budget
Land Base Investment Program	2011/12	Operating budget

Estimated annual costs for this project are shown to the end of fiscal 2017/2018 (year 10) in Appendix 1. Not shown are in-kind time of collaborators and BC MFML salaries of staff who over-see planning, site reconnaisance, sowing, lifting, layout, planting, site and climate station maintenance, data management, collaborator liaison, and contract supervision. Also, much of the seed was obtained *gratis* from BC Timber Sales, corporate donors and our collaborators, at a value of approximately $10,000/y.

8.0 Project Team

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9.0 Collaborators

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Tolko Industries – Don Wylie
Landmark Forest Management - Steve Giesbrecht
Sierra Pacific Industries – Mike Mitzel
West Fraser Mills – Guy Burdikin

Inland Empire Paper - Paul Buckland
ATCO Wood Products - Mark Macaulay
Island Timber – Brian Saunders
UBC Malcolm Knapp Research Forest - Ionut Aron
BC Timber Sales - Ellery Tetz, Walter Fister,
UBC Alex Fraser Research Forest – Ken Day
Tree Improvement Branch – Dave Reid, Rita Wagner, Keith Cox
Brinkman Forest Ltd – Marc Paquette
Ministry of Forests, Mines and Lands – Anna Monetta, Denis Petryshen, Brent Olsen, Mary Viszlai-Beale
Ardew Forest Products - Janice Stadey
Stella-Jones – Colin Pike
Yukon DNR - Rob Legare, Robin Sharples, Aynslie Ogden
Tembec – Klay Tindal
USDA FS – Gifford Pinchot National Forest/PNW Research Station – Todd Wilson
USDA FS – Mendocino National Forest – Chuck Frank/Tom Blush
USDA FS – Tahoe National Forest – Paul Stover/Tom Blush
USDA FS – Deschutes National Forest – Kayla Herriman/Brian Tandy
USDA FS – Priest River Exp Statn/Rocky Mountain Research Station – Bob Denner/ H. Todd Mowrer

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Assisted Migration Adaptation Trial - costs											
Activity	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	**Total**
Seed (years 1-4)	9000	1000	100	0							$10,100
Sowing (years 1-4) 8 p-d/y @ $300/p-d		2400	0	2800							
Travel, meal, accom for planting, fencing, survey, site recon (years 1-4)	25000	20000	20000	20000	10000	10000	10000	10000	10000	10000	$145,000
Seedlings: (year 1-4) 3200 seedling/site x 12 sites/y x 2.00 over-sow x $0.30/sdlng	23040	23040	20000	20000							$86,080
Lifting: (years 1-4) 18 p-d/y @ $300/p-d	5400	5400	6000	6000							$22,800
Machine site prep: (years 1-4) 3 sites/y x $5000/site	9000	9000	22000	25000							$65,000
Layout and staking: (years 1-4) 10 p-d/site x 12 sites/y x $400/pd (incl. travel)	48000	48000	48000	48000							$192,000
Pull wildlings, plant, sitemap: (years 2-5) 14 p-d/site/y x 12 sites/y x $400/p-d (incl travel)		57600	67200	50400	67200						$242,400
paint, stakes, flags, labels, pins (years 2-5) $1000/site/y x 12 sites/y		12000	12500	12500							$37,000
Meteorological equipment: (years 2-5) $1300/site x 12 sites/y		14000	15000	15000	16000						$60,000
Fencing: (years 2-5) 2 sites x $5000/site		10000	15000	11000	11000						$47,000
Survival survey (years 2-5) 12 sites x 2 pd x $400/pd			0	0	0						$0
Site maintenance and met download: (years 3-10) 4 p-d/site x 12 sites x $400/p-d (incl. travel)			19200	19200	19200	19200	19200	19200			$115,200
Extension, communications (years 1-4)	2000	2000	2000	1000	1000	1000	1000	1000	1000	1000	$13,000
Data collection: (years 5-8) 6 p-d/site/y x 12 sites/y x $400/p-d (incl travel)						28800	28800	28800	28800		
Weather data consolidation, screening and analysis 5d x 500/d			2500	2500	2500	2500	2500	2500	2500		
TOTAL	**$121,440**	**$204,440**	**$249,500**	**$233,400**	**$124,400**	**$59,000**	**$59,000**	**$59,000**	**$39,800**	**$11,000**	**$1,035,580**

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