Tree Species Adaptation Risk Management Project

Final Report Executive Summary

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This report describes the Tree Improvement Alberta's 3-year Tree Species Adaptation Risk Management project

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1.0 Background and scope

Climate is the primary natural selection pressure, which together with other natural phenomena such as day length (photoperiod) determines the population genetic architecture of plant populations. Thus, planning for acquisition and use of seed and vegetative planting materials in forestry and agriculture aim at maintaining a biological balance between plant populations and their environment. Plant hardiness zones in agriculture, and seed zones and breeding regions in forestry are the main tools agrologists and foresters use to ensure that seed and vegetative materials are collected and/or developed and planted in appropriate places. This proper use of planting materials serves to maintain genetic adaptation (survival, growth and reproduction) of the plants to their environment, which in turn, optimize use of plants for food, timber, pulp, amenities and other ecological goods and services we derive from health plant ecosystems.

Like other jurisdictions, Alberta has a system of seed zones that guides collection and use of seed and vegetative materials on public land. Likewise, the province has a system of breeding regions (also called controlled parentage programs or CPPs) that guide development and use of seed and vegetative materials from tree breeding programs. Both systems are regional land divisions aligned with the province's climatic patterns to provide a predictable framework for safer transfer of forest tree seed.

Alberta originally developed seed zones and breeding regions based on the need to adapt plant materials to the prevailing climate at that time. The climate is changing at a much faster rate than the rate of plant genetic evolution, which proceeds through reproduction over many generations. This is particularly true in forest tree species where a single generation may last for decades. At this slow rate of evolution, forest trees in cooler climates such as Alberta have a greater chance of lagging behind a changing climate thereby being exposed to mortality, low annual growth and reduced rates of reproduction. This potential reduction in reproductive fitness would in turn compromise the viability of the Alberta forestry industry; reduce reclamation success; expose forests to insects and diseases that prey on weather-stressed plants; loss of forest-dominated ecosystems in provincial and national parks that support the Alberta's tourist industry; and loss of forest ecosystems in areas that support fish and wildlife, rivers and streams on which the province's water supply depends. The economic conditions of forestry-dependent communities would suffer a great deal if a significant area of the province's productive forest land base was lost due to climate change. Therefore, climate change adaptation in Alberta's forests is greatly needed and timely.

Early attempts to adapt the province's forests to a changing climate began in the early part of the last decade by developing the Alberta climate model (ACM) to provide a tool for generating climate data based on latitude, longitude and elevation for any selected place in the province. The ACM was particularly important in isolated forest areas where coverage by weather stations is very sparse or non-existent. ACM enabled the province to relate climatic and biological data for some of the existing field experiments in order to generate information needed to modify seed transfer practices through the existing system of seed zones. In addition to gaining significant knowledge and its integration into seed transfer practices, the early work of climate change adaptation identified limitations of biological data from existing field experiments that were originally established to support tree breeding rather than climate change adaptation. Thus, the province needed to address these limitations if it were to adequately address climate change adaptation with sound science-based policy.

In 2012, the Climate Change and Emissions Management (CCEMC) Corporation initiated the Tree Species Adaptation Risk Management (TSARM) project to support the province in developing their climate change adaptation policy. The TSARM project sought to implement climate change adaptation-related activities in the Alberta government and industry tree improvement programs. These activities were aimed at producing and directing use of seed and vegetative materials on public land to ensure that future Alberta forests are wellbuffered to climate change through their genetic plasticity. The Alberta government and forest companies involved in tree breeding and tree improvement worked together in a consortium called Tree Improvement Alberta (TIA) to implement these activities in their respective programs.

Earlier work on climate change adaptation through careful use of seed and vegetative planting materials in Alberta concentrated on transfer of wild collected materials through the existing system of seed zones. Little attention was devoted to addressing concerns related to climate change adaptation with materials developed through tree breeding programs. Consequently, the TSARM project devoted two-third of its activities and resources to climate adaptation associated with tree breeding and tree improvement programs. This project built on the knowledge gained from wild seed transfers to address technical issues that are pertinent to development and use of genetically improved materials (through traditional breeding programs) within and across breeding regions.

This executive summary describes in general terms, the activities and outcomes of each subproject implemented as part of the overall three year TSARM project. TIA submitted annual progress reports to CCEMC describing in detail ongoing and completed activities as previously stipulated in the project implementation plan. Unlike the annual progress reports, this final project report is written in a format that facilitates easy public access and knowledge dissemination. The work and outcome of subprojects involving extended statistical and genetic analyses and synthesis have been developed into independent reports accompanying this executive summary. Likewise, the major project activities and outcomes and their linkage to provincial climate change adaptation policy have been compiled into an independent document that can be cited and distributed to stakeholders and the public. In addition, TIA has compiled CPP-specific outcome reports to be submitted to owners of the tree improvement programs to allow them to integrate project results into their future program planning and management.

2.0 Summary and outcomes of project activities

2.1 Development of expanded provenance trial sites

Earlier work on climate change adaptation showed that data from existing field experiments for both coniferous and deciduous species had limitations with respect to addressing future climatic stress, in particular, drought. Most of the existing experiments are located in prime forest activity areas with no resemblance to future Alberta climates that are predicted to be warmer and drier. Therefore, the TSARM project sought to extend provenance testing into dry areas of the province in particular and at much higher elevations than the existing sites. This will allow the province to do further provenance testing to simulate drought tolerance and also determine how much further populations from warmer climates at lower elevations can be moved to higher elevations where growing seasons are shorter and the risk of frost damages is high. The sites developed under the TSARM project are listed in Table 1. These sites were chosen to bridge climatic gaps in the sampling of field provenance and progeny testing environments identified in the existing conifer and aspen experiments.

In addition to testing native coniferous and deciduous species, these sites will also be used to test non-native species that have a potential for commercial utilization in Alberta, and which may be more of drought than Alberta spruces and pines.

Table 1: Test sites location and climatic description

LOCATION	LATITUDE (°N)	LONGITUDE (°W)	ELEVATION (m)	MAT (°C)	MCMT (°C)	MWMT (°C)	CI	NDD	GDD	FFP	MAP (m)	AMI
Muskeg (near Grande Cache)$^{+}$	53.89	118.72	1505	0.2	-11.7	11.4	23.1	1420	639	38	621	1.0
Coleman (near Blairmore)$^{+}$	49.73	114.47	1796	1.3	-10.0	13.0	23.0	1213	819	70	759	1.1
Machesis Lake North^{+}	58.37	116.57	310	-0.8	-21.4	16.6	38.1	2465	1351	96	389	3.5
Brooks (CDC South)$^{+}$	50.55	111.83	746	4.1	-12.5	18.4	30.8	1233	1737	113	333	5.2
Stevens Creek^{++}	52.69	116.00	1234	1.8	-11.5	14.0	25.5	1301	1030	74	604	1.7
Grande Prairie^{++}	54.78	118.65	724	1.9	-13.9	15.2	29.1	1520	1257	97	537	2.3
Cowpar^{++}	55.82	110.69	536	0.4	-18.4	16.2	34.6	2049	1324	103	511	2.6
Hay River^{++}	59.14	117.57	334	-2.1	-22.9	15.8	38.7	2758	1215	82	392	3.1

+ –Intended for conifer testing; ++ –intended for deciduous testing; MAT –mean annual temperature; MTCM –mean temperature for the coldest month; MTWM –mean temperature for the warmest month; CI –continentality index (MTWN *minus* MTCM); NDD –degree days below 0°C; GDD –degree days above 5°C; FFP –frost free period; MAP –mean annual precipitation; AMI = GDD/MAP.

2.2 *Climate change vulnerability and risk assessment of tree improvement programs*

The TSARM project completed an inventory of all 24 controlled parentage programs (CPP) in Alberta with an emphasis on parental composition; field experiments; seed orchards; seed production; genetic diversity; distribution of the CPP deployment land base and parent selections into elevation and latitudinal bands (expected to represent climatic variation within the CPP region); alignment between the climate of the parent trees and that of the approved deployment region; and continuous assessment and measurement of field experiments. The purpose for this work was to gauge the strengths and weaknesses of these programs given that the flexibility to reorganize/redesign a program to meet the changing reforestation needs are part of a program's resilience. In addition, the information compiled under this project enables us to see how different tree improvement programs overlap in terms of their parental composition and field testing. These overlaps may be used to reorganize programs, share field measurement data, share parent trees and seed as part of a climate change adaptation strategy, which may require different suites of genotypes. Information from this subproject has been compiled in separate CPP-specific reports made available to CPP owners.

Some statistics from tree improvement programs are as follows:

- CPP region sizes range from 79,000 to 5,200,000 ha (the two smallest programs have a conservation focus).
- The number of genotypes included in breeding populations ranges from 27 (one of the conservation programs) to 715.
- Most programs have only one seed orchard; one program has two, and one has three.
- Target seed production ranges from 0.86 kg to 32.5 kg per year.
- The number of genotypes included in seed orchards ranges from 18 to 190.
- The number of trees in seed orchards for a single CPP program ranges from 80 to 4,115.
- The estimated cumulative effective population size (Ne), which is a measure of genetic diversity for the output of the seed orchards for each program, ranges from 5.9 (a conservation program) to 184.
- Total seed produced per program to date ranges from 0.17 kg to 774 kg.

It is recommended that even though the levels of genetic diversity, as measured by the effective population size (Ne), are high for most programs, a low Ne for a few programs may contribute to their vulnerability and higher risk under climate change. This program weakness should be addressed where it exists. Higher Ne levels are needed to buffer the population against a changing and uncertain climate. A higher Ne also allows a program to be modified to meet the changing economic needs and other environmental challenges. In addition, progeny testing in general should be expanded, with tests established over a wider range of sites, to allow us to cope with future uncertainty.

2.3 Climate modeling and analysis of biological data in CPP plans

As previously mentioned, earlier work on climate change adaptation in Alberta was largely focused on movement of wild seed through a system of Alberta seed zones. The TSARM project extended similar analyses to CPP-based measurements from field experiments (progeny and provenance trials). These analyses would allow the province to see differences and similarities among CPP regions from the way families and parent trees or clones grow when transferred among CPP regions. In turn, this would reveal the extent to which seed and vegetative planting materials can be transferred among CPP regions for reforestation and reclamation. To do this work, field experiments that were lagging behind in their measurements were all remeasured to obtain the latest growth data. Experiments measured under the TSARM projects are listed in Table 2.

Table 2: Clonal seed collections and field measurements statistics by CPP regions

CPP PLAN	SPECIES	PROGRAM OWNERS	CLONES/FAMILIES[+]	CLONES/FAMILIES[++]	SITES MEASURED
A	Lodgepole Pine (Pl)	West Fraser (Hinton Wood Products -HWP)	36	36	6
B1	Lodgepole Pine (Pl)	Alberta Newsprint Company (ANC), Canfor & Weyerhaeuser	190	97	3
B2	Lodgepole Pine (Pl)	West Fraser (HWP) & Weyerhaeuser	110	107	3
C	Lodgepole Pine (Pl)	West Fraser (Blue Ridge Lumber -BRL)	76	0	0
K1	Lodgepole Pine (Pl)	Alberta government & West Fraser (Sundre Forest Products -SFP)	67	4	2
J	Lodgepole Pine (Pl)	Alberta government, Tolko High Level, Manning Diversified Forest Products (MDFP)	84	12	0
P1	Jack Pine (Pj)	Alberta government & Northland Forest Products (NFPL)	58	19	0
M	Western Larch (Lw)	Alberta government	18	0	0
D	White Spruce (Sw)	West Fraser (BRL)	46	42	0
D1	White Spruce (Sw)	Alberta government	82	0	0
E	White Spruce (Sw)	Alberta government	97	0	0
E1	White Spruce (Sw)	Alberta government & Northland Forest Products (NFPL)	83	29	0
E2	White Spruce (Sw)	Alberta government	34	0	0
G1	White Spruce (Sw)	Canfor & Weyerhaeuser	139	135	4
G2	White Spruce (Sw)	Alberta government, Tolko High Level, Manning Diversified Forest Products (MDFP)	106	27	0
H	White Spruce (Sw)	Alberta government	68	0	0
I	White Spruce (Sw)	ANC, HWP, Millar Westen Forest Products (MWFP) & Weyerhaeuser	172	172	5
F1	Interior Douglas Fir (Fdi)	Alberta government	39	0	0
L1	Black Spruce (Sb)	ANC, HWP & MWFP	138	0	1
L2	Black Spruce (Sb)	Canfor & Weyerhaeuser	68	31	2
L3	Black Spruce (Sb)	Alberta government	41	0	0
Research	Scots Pine	Alberta government			3
Pb1	Balsam Poplar (Pb)	Alberta Pacific Forest Industries (Al-Pac)	520	NA	3
Aw1	Trembling Aspen (Aw)	Ainsworth, Dishowa Marubeni & Weyerhaeuser	427	NA	27
Aw2	Trembling Aspen (Aw)	Ainsworth, Dishowa Marubeni & Weyerhaeuser	498	NA	5
TOTAL				**711**	**64**

+ -number of families and parents (clones) in the CPP plan; ++ -number of families or clones from which seed were collected.

For this subproject, TIA hired a Postdoctoral Fellow in the Department of Renewable Resources at the University of Alberta to pursue two lines of inquiry:

i. Perform climate modeling to determine future climates for the province as a whole and for individual CPP regions.
ii. Using climate data and growth measurements from field experiments, analyze the relationship between tree growth and climate to determine how growth of families, clones and populations is affected when these genetic entities are planted within and outside of their native CPP regions.

The details on data, methodology, outcomes, inferences and practical implications of this work are submitted in two comprehensive independent reports listed below.

a) "*Projected Changes in Climate for Alberta and Forest Tree Improvement Program Regions*" by Laura K. Gray and Andreas Hamann, Department of Renewable Resources, University of Alberta, Edmonton. 100 pages.

b) "*Climatic Adaptation of White Spruce and Lodgepole Pine in Alberta Controlled Parentage Programs*" by Laura K. Gray and Andreas Hamann, Department of Renewable Resources, University of Alberta, Edmonton. 21 pages.

The major conclusions from this subproject are as follows:

1) Alberta is predicted to be warmer and drier with a greater increase in temperature during winter months, especially in the northern part of the province.
2) Only a moderate increase in annual precipitation is expected in areas of the province (parkland and boreal forest regions that are normally dry) and in the foothills.
3) Nevertheless, the moderate increase in annual precipitation will be outpaced by a rapid increase in spring and summer heat (degree days above 5^{o}C, also called growing degree days or GDD) leading to an overall moisture deficit.
4) Although some adjustments could be made to allow seed transfers across CPP regions, results show that, at this time, local seed is still the best choice for reforestation in all conifer CPP regions. It should be noted however, that the analysis was limited to the relationship between growth and climate in white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) which make up over 80% of all tree planting on public lands in Alberta. Traits responsible for success in stand establishment, which were not assessed in these experiments, may be affected differently by climate change.

In addition to the two species-specific reports submitted with this summary, two manuscripts, one on white spruce and one on lodgepole pine will be submitted for peer review and publication. Other products in this subproject includes:

a) A searchable database that allows tree improvement program owners to find performance information on parent trees from their own and other programs for potential sharing of plant material and/or collaboration in field testing and sharing of measurement data.
b) Field measurement data previously scattered across the 24 individual tree improvement program databases were assembled into a single comprehensive database making access to this data profoundly easier for both research and planning purposes that cut across many programs.

2.4 Development of efficient propagation methods for aspen

In a natural forest, aspen regenerate naturally through a network of roots that began as a single tree from a seed that germinated at a particular point in time. Some of the present wild aspen clones that form much of the Alberta aspen forests arose from seed that may have germinated thousands of years ago. Aspen is a difficult species to artificially propagate in the nursery. Consequently, even if clones suitable for the future climate are identified, the high cost of producing a plantable aspen propagule would hinder this approach to addressing climate change adaptation. Working with Woodmere Nursery, Smoky Lake Forest Nursery and Bonnyville Forest Nursery, the TSARM project attempted different vegetative propagation methods with a target of reducing the cost per plantable propagule to $0.50 - $0.60. From this work, the cost per plantable propagule was $1.01 to $1.52, which is still reasonably high and not an economically viable alternative to growing seedlings. However, given that the rooting ability was highly variable among clones, it is expected that identifying easier-to-root clones, combined with economies of scale associated with operational reforestation as opposed to small-scale production in a research setting, should allow the cost per plant to be lowered to $0.70 - $0.80. Details of this subproject are submitted as an independent report.

2.5 Seed collection by clones and seed orchard design

As part of the climate change adaptation project, seed was collected from each clone or family in each seed orchard, processed and stored individually for future field progeny testing and other adaptation-related research. The number of clones from which seed collections were made within each CPP region is provided in Table 2.

2.6 Integrating adaptation in progeny trials

In the three-year period of the TSARM project, region D and E1 (white spruce) and J (lodgepole pine) established progeny trials as part of their prior scheduled field testing to support their tree breeding programs. The TSARM project used this opportunity to include in these trials, many provenances and families from other programs and other regions of the province including those not currently covered by any breeding programs. White spruce provenances from Saskatchewan, Manitoba, Ontario and Quebec which have shown greater growth superiority over local Alberta provenances in previous studies were also included in these new trials. These out-of-CPP provenances and families will serve to increase the province-wide value of data generated from these field experiments by enabling us to statistically analyze the possibility of using selected parent trees across CPP regions. In total, the new 14 field experiments designed and established with this approach will have better climate change adaptation value than previous progeny trials.

2.7 Stakeholder engagement and education

Climate change adaptation begins with the realization and acceptance that the climate is changing, changes will affect the forestry business, and there are measures that can be integrated into existing operations to reduce the potential negative impacts. Therefore, stakeholder education is part of the provincial climate change adaptation strategy. The TSARM project conducted three stakeholder workshops, one each year, and two visits to field experiments in southwestern and northwestern Alberta. Project participants and representatives from relevant government departments, the University of Alberta and other academic institutions including the Canadian Forest Service, Alberta Innovates, Northern Alberta Institute of Technology, and the Alberta Forest Genetic Resources Council attended these technology transfer sessions. Invited speakers from the climate change adaptation groups in British Columbia, University of Regina, Canadian Forest Service and the University of Alberta presented their work at the workshops. CCEMC representatives also attended these sessions and presented the CCEMC climate change adaptation and mitigation goals. Project participants reviewed the project progress and its potential impacts to their operations. Other subjects such as potential climate change adaptation for forest insects and diseases, which were not part of the original project planning but are becoming increasingly important, were integrated into the workshop and field visits by inviting relevant subject matter experts to speak. Workshops and field tours have not only helped to advance our understanding of climate change adaptation through forest genetics and tree improvement in Alberta, but have also helped to create a strong network among tree breeders, foresters and researchers that will strengthen tree improvement in Alberta beyond the TSARM project.

3.0 Challenges in the project implementation

The TSARM project was one of the only first three climate change adaptation projects to be funded by the CCEMC. Thus, in addition to implementing the planned activities, the project was asked to document challenges encountered during project implementation as a learning opportunity for CCEMC. CCEMC has previously been funding climate change mitigation only and therefore asked to be made aware of issues unique to administering a climate change adaptation project.

Challenges encountered by the TSARM project are listed below:

i. The TSARM project was a biological climate change adaptation project whereby implementation of some of the planned activities depended on the biological rhythms and reproductive cycles of conifers. For example, a planned 2012 seed collection by clone in conifer seed orchards could not be implemented because 2012 a very low cone production year for spruce. Because conifer cone production typically cycles on a three - five-year interval and is not easy to predict, one has to be ready to transfer planned activities to subsequent years, thus requiring amendments and approval of annual project implementation plans.

ii. The TSARM project test sites require consultation with First Nations in order to secure the required land dispositions. Consequently, the development of the test sites was repeatedly rescheduled to accommodate this consultation, requiring amendments and approval of annual project implementation plans.

iii. Some of the project activities, such as test site development, involved field work done by contractors. Costs for these activities fluctuated with labour demands that are often encountered in Alberta. This need to hire contractors introduced several variances into the budget requiring amendments and approval of annual project implementation plans.

4.0 Future research and adaptation priorities

As the TSARM project wraps up, there are other climate change-related challenges facing the Alberta forest industry and reclamation and revegetation areas disturbed by energy development that need to be addressed. Recent observation shows that the following activities are of high priority for research and climate change adaptation funding.

i. ***Establishing experiments (trials) on sites developed by the TSARM project****:* –Establishing field experiments on sites developed by the TSARM project will have to occur as soon as possible to prevent these sites from being recolonized by wild trees, shrubs and other vegetation thereby requiring redevelopment of the site in the future. In addition, the scientific and climate change adaptation value of these sites will be fully realized only when experimental trees are planted on them.

ii. ***Insects and diseases***: In recent years, there have been unexpected outbreaks of native and non-native fungal diseases in existing field experiments and seed orchards. Undoubtedly, these diseases are likely to be found in wild populations of the same tree species if deliberate surveys of wild forest stands were conducted. Insect and disease incidences and outbreaks are expected to increase as the climate changes and the province becomes hospitable to species of insects and fungi that would normally not survive Alberta winters. Therefore, there is a need to invest in research and development of insect and disease tolerant trees as part of an ongoing provincial climate change adaptation strategy.

iii. ***Population genetics of shrubs***: - Shrubs are an integral component of reclamation and revegetation on sites disturbed by energy development in Alberta. Beginning in the fall of 2015, use of shrub seed and vegetative planting materials will be regulated under the revised Alberta Forest Genetic Resource Management and Conservation Standards (FGRMS). Because the knowledge of population genetics of shrubs derived from direct field experimentation (provenance trials) is lacking, transfer of shrub seed and vegetative material for reclamation in Alberta will provisionally be regulated by the same standards that control the transfer of forest tree seed and vegetative material. Undoubtedly, shrubs used in reclamation will face the same climate change-related challenges as forest trees used in reforestation. Therefore, provenance testing for the major reclamation shrubs in Alberta is one of the high priority areas needing new funding in the immediate future.

5.0 Acknowledgements

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6.0 Accompanying independent reports

Laura K. Gray and Andreas Hamann. 2015. Projected Changes in Climate for Alberta and Forest Tree Improvement Program Regions. Department of Renewable Resources, University of Alberta, Edmonton. 100 pages.

Laura K. Gray and Andreas Hamann. 2015. Climatic Adaptation of White Spruce and Lodgepole Pine in Alberta Controlled Parentage Programs. Department of Renewable Resources, University of Alberta, Edmonton. 21 pages.

Deogratias Rweyongeza, Barb R. Thomas, Shane Sadoway and Dawn Griffin. 2015. Public Policy Linkages for the Tree Species Adaptation Risk Management Project in Alberta. Tree Improvement Alberta, Edmonton. 6 pages.