Tree Species Adaptation Risk Management Project

Final Report

July 2015

Project Duration – April 1, 2012, through March 31, 2015

Project Manager – Daniel Chicoine

This report describes Tree Improvement Alberta's (TIA's) three-year Tree Species Adaptation Risk Management project.

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Suggested citation

Final Report to the Climate Change and Emissions Management Corporation. 2015. Prepared for the Tree Species Adaptation Risk Management Project Adaptation project. Tree Improvement Alberta, Edmonton, AB, 57 pages.

The project receives its core funding from the CCEMC.

CCEMC
Climate Change & Emissions
Management Corporation

Contents

About TIA

Tree Improvement Alberta (TIA) is a consortium of Alberta forest industry and provincial government representatives working together to facilitate the delivery of programs and projects related to forest genetics in Alberta. TIA is hosted by the Foothills Research Institute and is the contracted party with the Climate Change and Emissions Management Corporation (CCEMC).

TIA comprises the following participating members—Alberta Agriculture and Forestry (formerly Alberta Environment and Sustainable Resource Development), Alberta Newsprint Company, Alberta-Pacific Forest Industries, Blue Ridge Lumber, Canadian Forest Products, Daishowa-Marubeni International, Hinton Wood Products, Manning Diversified Forest Products, Millar Western Forest Products, Norbord (formerly Ainsworth Engineered), Northland Forest Products, Sundre Forest Products, Tolko Industries, Weyerhaeuser Pembina, and Weyerhaeuser Grande Prairie.

TIA is governed by a board of directors made up of select participating members and the University of Alberta.

TIA was initially brought together to facilitate the delivery of the Tree Species Adaptation Risk Management (TSARM) project.

About the CCEMC

The Climate Change and Emissions Management Corporation (CCEMC) is an Alberta-based, independent, not-for-profit organization incorporated under the *Canada Corporations Act* on February 17, 2009, whose operations commenced on June 1, 2009. The CCEMC's mandate is to reduce greenhouse gas emissions and adapt to climate change by supporting the discovery, development, and deployment of clean technologies. The Climate Change and Emissions Management Fund was established under the *Climate Change and Emissions Management Act* by the Government of Alberta to support investment in innovation and clean technologies that will reduce Alberta's greenhouse gas emissions and improve its ability to adapt to climate change. The fund provides the primary source of revenue for the CCEMC.[1]

Acknowledgements

TIA acknowledges access to data provided by the Government of Alberta (Agriculture and Forestry, formerly Environment and Sustainable Resource Development), Alberta-Pacific Forest Industries Inc., ANC Timber Ltd., Canadian Forest Products Ltd., Daishowa-Marubeni International Ltd., Manning Diversified Forest Products Ltd., Millar Western Forest Products Ltd., Norbord Inc. (formerly Ainsworth Lumber), Northland Forest Products Ltd., Tolko Industries Ltd., West Fraser Mills Ltd. (Hinton Wood Products, Sundre Forest Products Inc., and Blue Ridge Lumber Inc.), Weyerhaeuser Company Ltd. (Grande Prairie and Pembina Timberlands).

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[1] Climate Change and Emissions Management Corporation (CCEMC). *Global Challenges. Local Solutions*. ccemc.ca. p. 44.

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Executive Summary

1.0 Background and Scope

Climate is the primary natural selection pressure that, together with other natural phenomena such as day length (photoperiod), determines the genetic architecture of plant populations. Thus, planning for acquisition and use of seed and vegetative planting materials in forestry and agriculture aims to maintain 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 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 optimizes use of plants for food, timber, pulp, amenities, and other ecological goods and services we derive from healthy 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 Alberta's forestry industry, reduce reclamation success, expose forests to insects and diseases that prey on weather-stressed plants, cause the loss of forest-dominated ecosystems in provincial and national parks that support Alberta's tourist industry, and cause the loss of forest ecosystems in areas that support fish and wildlife and the 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 were 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 with the development of 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. The 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 integrating it 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 in order to adequately address climate change adaptation with sound science-based policy.

In 2012, the Climate Change and Emissions Management Corporation (CCEMC) initiated the Tree Species Adaptation Risk Management (TSARM) project to support the Province in developing climate change adaptation policy. The TSARM project sought to implement activities related to climate change adaptation in 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 well buffered against 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-thirds 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 developing and using 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 the 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 linked to in this report. 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 the 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, particularly drought. Most of the existing experiments are located in prime forest activity areas with no resemblance to future Alberta climates, predicted to be warmer and drier. Therefore, the TSARM project sought to extend provenance testing into dry areas of the province 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 damage 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 potential for commercial use in Alberta and that may be more drought-resistant than Alberta spruces and pines.

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.

Table 1: Test sites location and climatic description.

2.2 Climate Change Vulnerability and Risk Assessment of Tree Improvement Programs

The TSARM project completed an inventory of all 24 CPPs in Alberta. The inventory emphasized 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 of this work was to gauge the strengths and weaknesses of these programs, given that the flexibility to reorganize/redesign a program to meet changing reforestation needs is 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, and 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 hectares (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 kilograms to 32.5 kilograms 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 kilograms to 774 kilograms.

It is recommended that even though the levels of genetic diversity, as measured by the 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 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 Modelling 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 between 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.

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.

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

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:

- Perform climate modelling to determine future climates for the province as a whole and for individual CPP regions.
- Use climate data and growth measurements from field experiments to 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:

- *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. 2015. 100 pages.

- *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. 2015. 21 pages.

The major conclusions from this subproject are as follows:

- 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.
- 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.
- Nevertheless, the moderate increase in annual precipitation will be outpaced by a rapid increase in spring and summer heat (degree days above 5°C, also called growing-degree days or GDD) leading to an overall moisture deficit.
- 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 linked to in this report, two manuscripts, one on white spruce and one on lodgepole pine, will be submitted for peer review and publication. Other products in this subproject include:

- A searchable database that allows tree improvement program owners to find performance information on parent trees from their own and other programs for potentially sharing plant material and/or collaborating in field testing and sharing measurement data.
- A single comprehensive database of field measurement data previously scattered across the 24 individual tree improvement program databases, making access to this data profoundly easier for 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 propagate artificially 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. This work achieved a cost per plantable propagule of $1.01–$1.52, which is still relatively 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 provided on page 47 of this 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, and 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, regions 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 many provenances and families from other programs and other regions of the province, including those not currently covered by any breeding programs, in these trials. 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 14 new 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, that changes will affect the forestry business, and that 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, the University of Regina, the 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 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 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 the CCEMC. The CCEMC has previously only funded climate change mitigation 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:

- The TSARM project was a biological climate change adaptation project, so implementing 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 was a very low cone production year for spruce. Because conifer cone production typically cycles on a three- to 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.
- 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.
- Some of the project activities, such as test site development, involved fieldwork done by contractors. Costs for these activities fluctuated with the changing 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:

- **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.
- **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.

- **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

TIA acknowledges access to data provided by the Government of Alberta (Agriculture and Forestry, formerly Environment and Sustainable Resource Development), Alberta-Pacific Forest Industries Inc., ANC Timber Ltd., Canadian Forest Products Ltd., Daishowa-Marubeni International Ltd., Manning Diversified Forest Products Ltd., Millar Western Forest Products Ltd., Norbord Inc. (formerly Ainsworth Lumber), Northland Forest Products Ltd., Tolko Industries Ltd., West Fraser Mills Ltd. (Hinton Wood Products, Sundre Forest Products Inc., and Blue Ridge Lumber Inc.), Weyerhaeuser Company Ltd. (Grande Prairie and Pembina Timberlands).

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6.0 Accompanying Independent Reports

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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.

In-Kind Contributions

As part of the implementation of the TSARM project, industry and government have contributed over $5.6 million in project administration, tree improvement work directly related to the project activities, travel costs, meeting time, etc. The TSARM project builds on the significant historical investment that the Government of Alberta and the Forest Industry have made in tree improvement and provenance / progeny testing and further accentuates the value of these assets to the people of Alberta.

Project Linkages to Public Policy

There are six key areas in which the TSARM project has contributed to the understanding of potential required changes or additions to public policy (see Appendix 1 TSARM_PolicyLinkage_2015Jul20.pdf for a complete report on linkages of the TSARM project to public policy).

1.1 Development of Expanded Provenance Trial Sites

The work done: The TSARM project completed development of three large experimental sites (≥ 15 hectares each) and completed the land survey and reservation of a fourth site (8 hectares). These sites will provide sufficient experimental space for conifer provenance trials in climates where field experimentation has not been conducted before. In addition, the project completed surveys and land reservations for four sites earmarked for field experimental space for deciduous species, mainly aspen and balsam poplars. These sites are located in places where deciduous species have not been tested before.

Linkage to policy: Developing large field experimental sites carries a high one-time cost, which limits the ability of the GOA and industry to generate research data that support the development of seed-transfer guidelines and climate change adaptation policy. Therefore, even though the actual planting of experimental trees will follow later under separate funding, the TSARM project has advanced the ability of the GOA and industry to address climate change adaptation by creating a research environment that supports policy development.

1.2 Climate Change Vulnerability and Risk Assessment of Tree Improvement Programs

The work done: The TSARM project inventoried parental composition, field experiments, seed orchards, seed production, genetic diversity, distribution of the CPP deployment land base 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 for all 24 CPP regions. The rationale for this work was to gauge the strength and weakness of these programs given that the flexibility to reorganize or redesign a program to meet changing reforestation needs is part of a program's resilience.

Linkage to policy: Under the FGRMS, Alberta has established a minimum allowable level of genetic diversity before propagules from CPP programs can be used on public land, and the climatic sampling of both parent trees and experimental environments. The information and reports generated by the TSARM project will enable the CPP owners to address weaknesses in their programs in line with the existing provincial standards. The FMB is currently working on a directive to require mandatory use of orchard seed whenever available before considering use of wild seed. Part of the rationale for this directive is to maintain forest productivity and wood supply on a shrinking productive commercial forestry land base that is being impacted by climate change. Therefore, strengthening the adaptability (flexibility) of breeding programs to meet the changing reforestation challenges and needs will aid GOA climate change adaptation policy initiatives.

1.3 Climate Modelling and Analysis of Biological Data

Prior to TSARM, work by the GOA and the University of Alberta on climate change adaptation of conifers and aspen, respectively, focused on transfer of wild seed and clones across seed zone boundaries. In contrast, the TSARM project work focused on transfer of seed and clonal material from tree breeding programs across breeding region (CPP region) boundaries.

The work done: Field height growth measurement data from all nine white spruce and six lodgepole pine breeding regions were compiled and analyzed to examine the potential of seed transfer across regions in light of the projected changes in Alberta's climate. Although some adjustments could be made to allow seed transfer across CPP regions, results show that, at this time, local seed is still the best choice for reforestation in all conifer CPP regions.

Linkage to policy: From the GOA perspective, local seed being the most suitable for reforestation within the CPP region implies that no drastic change in the standards governing collection and use of seed from tree breeding programs is warranted in the short to medium terms. However, because populations (provenances) and parent trees (clones) grow differently across CPP boundaries when examined individually instead of based on the average growth of the entire CPP seed crop, results from the TSARM project will enable the GOA to allow greater and targeted sharing of tree breeding material (parent trees) across CPP regions. This allows climate change adaptation measures to be implemented in targeted sections of the CPP regions without altering CPP region boundaries. It also provides information for identifying and removing individual parent trees that are climatically unsuitable for the CPP region from seed orchards.

1.4 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 propagate artificially in the nursery. Consequently, even if clones suitable for the future climate were identified, the high cost of producing a plantable aspen propagule would hinder climate change adaptation.

The work done: Working with Woodmere Nursery, Smoky Lake Forest Nursery, and Bonnyville Forest Nursery, the TSARM project attempted different vegetative propagation methods to try to reduce the cost per plantable propagule to \$0.50–\$0.60. This work achieved a cost per plantable propagule of \$1.01–\$1.52, which is still relatively high. However, given that rooting ability varied 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 be able to lower the cost per plant to \$0.70–\$0.80.

Linkage to policy: From a policy perspective, climate change adaptation options have to be fiscally feasible; otherwise, they will never be operationally implemented. Thus, a significant reduction in the propagation cost is an initial step toward implementing provincial aspen clonal deployment standards that have recently been developed in the revised FGRMS (fall 2015).

1.5 Stakeholder Engagement and Climate Change Adaptation

Climate change adaptation begins with the realization and acceptance that the climate is changing, that changes will affect the forestry business, and that there are measures that can be integrated into existing operations to lower negative impacts. Therefore, stakeholder education is part of the provincial climate change adaptation strategy.

The work done: In three years, 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, and the Canadian Forest Service attended these learning sessions. Invited speakers from the climate change adaptation groups in British Columbia, the University of Regina, the Canadian Forest Service, and the University of Alberta presented their work at the workshops. Participants reviewed the TSARM project progress and its potential impact to their operations. Other subjects that were not part of the original project planning but that are becoming increasingly important, such as potential climate change adaptation for forest insects and diseases, were integrated into the workshop and field visits by inviting relevant speakers.

Linkage to policy: Stakeholder engagement has been one of the most successful parts of the TSARM project. Before the beginning of the project, there was very limited understanding and acceptance of why the GOA restricts collection and use of seed and vegetative materials on public land within a system of seed zones and region-based breeding programs. Workshops presenting data from Alberta and British Columbia forest genetics research programs, and visits to field experiments to physically see differences in growth among trees from different seed sources, have helped significantly in changing that. Climate change adaptation is now becoming an integral part of tree breeding field trials being planned by forest companies and a consideration in province-wide reforestation activities.

1.6 Institutional Strength

In addition to addressing the specific climate change adaptation objectives identified in the project implementation plan, the TSARM project has helped to establish a close working relationship between GOA departments and agencies such as Alberta Innovates Bio Solutions, forest companies, academic and research institutions both within and outside Alberta, and the Foothills Research Institute. This alliance, forged through Tree Improvement Alberta (TIA) and stakeholder workshops and field tours, will be a great asset in the future when addressing technical and policy issues related to climate change, tree breeding, forest insects and diseases, and forest research as a whole.

Key Findings

Performance Indicators

	Indicators	Policy	Practice
	Challenges What are the challenges encountered during the course of the project? How were they overcome or addressed?	How might the challenges encountered during the course of the project inform any current policy or potential future adaptation policy?	How might the challenges encountered in this project inform or impact any current practice or future adaptation programming?
	Learnings What are the key learnings in the project so far, how have they been established, and how have they been documented?	How does this project enhance our understanding of adaptation and adaptation-related policy? What are the linkages between key learnings from the project and existing policies, or a future adaptation policy?	How might the key learnings from the project inform current practices or programming in Alberta? What are the linkages between the project learnings and potential future adaptation practices and programming?
	Innovations What innovation or new knowledge on adaptation has emerged from this project?	How might innovation stemming from this project impact existing or future adaptation-related policies?	How might project innovations impact adaptation-related projects and programs?
Adaptation risk assessments for CPP regions	**Challenges** Ensuring that all CPPs in Alberta were assessed consistently for their risk due to climate change. To overcome this challenge, a team developed a template that was used for reviewing the 24 (10 in-kind) existing CPPs.	The outcome of these CPP reviews will inform potential new transfer guidelines for orchard seed or clonally propagated deciduous species.	Material from CPP plans may be distributed differently across the landscape and be used by companies outside the original design of a given program.
	Learnings Template reviews are complete for all 24 of the CPP plans, with compilations, including recommendations for consideration, being provided to proponents.	The outcomes from this project are critical in informing new and changed policy regarding deployment of seed and propagules across the province. Key learnings will directly	Placement of deployed stock across the landscape will likely change. Integration across regional boundaries will be better informed and supported for future

	Key findings are being published as per the Climate Adaptation section of this report.	impact both existing and new policy.	policy changes.
	Innovations New knowledge will emerge as the result of evaluating existing programs under a changed climate regime typically not considered when most of these programs were developed.	Policy related to seed-transfer guidelines will be better informed and more robust to buffer against predicted climate change in Alberta.	Adaptation is always considered in tree improvement programs; however, going forward, adaptation specifically related to climate change will have a significant impact on development of these programs and on redesigning future production of seed/propagules.
Adaptation test sites	**Challenges** Expanding the knowledge base for appropriate climate test sites for commercial tree species in Alberta. Identifying and being able to secure test sites has been completed. Four coniferous and four deciduous sites were identified in appropriate locations with preferred moisture and temperature extremes.	Site selection is critical to informed decision making on future seed-transfer guidelines used for all reforestation in Alberta where natural regeneration is not an option.	Seed movement standards are critical for forest companies to manage their reforestation requirements, and changes will impact both collection protocols and deployment options.
	Learnings This project has ensured that the right sites are being selected for future testing of commercial species. Installing test trees was not part of this project. Site selection is, however, critical to successfully gaining information in the future.	Appropriate site selection has a major impact on results to be obtained from future testing on these sites and will directly influence policy related to deployment.	This project has guided practitioners on how to appropriately move materials to assist with adaptation and will influence future adaptation practices and programs.

	Innovations Test sites have previously not been placed in locations that test the “extremes” of climate in a region. This is a new approach, taking testing outside of mesic, average and previously typical deployment areas and regions.	Placement of test sites in locations with extreme climates will inform reforestation policy for deploying materials.	Material collection sites may change, and deployment of standard reforestation programs will be guided through science-based policy.
Orchard management, seed assessments and collections	**Challenges** Maintaining and obtaining appropriate material to install in progeny tests that will inform decisions on future seed orchard design and parental selection has not been possible prior to funding of this project. Individual family/clone cone collections have been undertaken to provide this material (see Table 3).	Future orchard designs and decisions about including or excluding parents producing seed for future deployment will be impacted by this work. Policy allowing for including new parents into existing programs will also be informed and likely change the boundaries for deployment of seedlots.	Appropriate parents being included and excluded in production orchards will change programs significantly.
	Learnings Collection methods by family or clone have been developed and applied.	Individual collections will allow for much more detailed information to be obtained, rather than using bulked orchard seedlots in test sites. Future deployment can be better targeted using the “right” parents, as those less well adapted can be removed from orchards. Changes in policy will be needed to allow for both removal and inclusion of parents.	If deployment areas targeted for a specific orchard change, then collaboration between companies will be required to both access material and support ongoing production.
	Innovations This is part of a longer-term initiative and will provide flexibility for future testing.	Identifying individual parents or selection regions will be possible, and maladapted material can be removed from production.	Regions for current seed deployment from existing seed orchards are likely to change.

Aspen clonal propagation trial	**Challenges** Reducing the cost of producing selected superior aspen so that deployment is economical using this material. Three nurseries were challenged with developing a propagation technique and providing an economic analysis.	Having the ability to deploy native aspen clonally (economically) will assist with adaptation policy related to assisted migration of an important commercial species.	Without this technology, clonal deployment of superior native aspen will not be possible.
	Learnings Reports from the nurseries outline the opportunities and challenges associated with growing aspen economically and provide options.	The most recent revisions to the policies governing deployment have enabled the deployment of clonal species.	Deployment options on the ground for FMA holders have been expanded with respect to clonal species.
	Innovations This technology will allow forest companies in Alberta to take advantage of new knowledge regarding adaptation in a species typically regenerated naturally.	It will allow for implementation of new policy related to climate adaptation using clonal material versus seed.	Assisted migration will be possible with superior native aspen if warranted under climate change.
Field trial measurements (conifer and deciduous)	**Challenges** There are many provenance and progeny trials throughout the province but many are specific to a particular area or region with a specific purpose in mind. Completing new measurements on these sites can provide valuable information to assist in developing new trial sites.	Measurement information has been fed into climate and genetic model scenarios to assist with a science-based approach to influencing potential changes to policy and developing new policy.	Measurement data has provided information on top performers and potential insect and disease resistance to help practitioners make better decisions for deployment.
	Learnings Measurement data has been provided to assist in analysis to determine trends and look for potential risks of tree movement. The outcomes	Measurement data and analysis have informed policy (particularly the most recent review of the FGRMS guidelines) of dos and don'ts for tree movement guidelines in	The current practice may be different for deployment variances, given the performance of parents from certain locations and how the amount of change from

	are being published by Dr. Laura Gray of the University of Alberta.	Alberta.	their original location impacts things such as survival, growth, and insect and disease resistance.
	Innovations The trial measurement data has been fed into analyses and has provided tools to assist in determining top and bottom performers to more quickly provide a means for assisted migration and adaptation of critical genotypes.	The measurement data and analysis will inform policy of necessary changes or modifications required to ensure material deployed is well adapted.	The data will inform changes in deployment practice and help ensure that maladapted materials do not get deployed.

CPP Program	Species	Entity	# of Clones/ Families	# Clones/Families Seed Collected	Test Sites Measured		
A	Lodgepole Pine (Pl)	West Fraser (HWP)	36	36	6		
B1	Lodgepole Pine (Pl)	HASOC (ANC 22.3%, Canfor 37.5%, Weyer 40.2%)	190	97	3		
B2	Lodgepole Pine (Pl)	HASOC (HWP 46.7%, Weyer 53.3%)	110	107	3		
C	Lodgepole Pine (Pl)	West Fraser (BRL)	76	0	0		
K1	Lodgepole Pine (Pl)	SRD & West Fraser (Sundre)	67	4	2		
J	Lodgepole Pine (Pl)	FGAA (MDFP, SRD, Tolko)	84	12	0		
P1	Jack Pine (Pj)	FGAA (Northland, SRD)	58	19	0		
M	Western Larch (Lw)	SRD	18	0	0		
D	White Spruce (Sw)	West Fraser (BRL)	46	42	0		
D1	White Spruce (Sw)	SRD	82	0	0		
E	White Spruce (Sw)	SRD	97	0	0		
E1	White Spruce (Sw)	FGAA (Northland, SRD)	83	29	0		
E2	White Spruce (Sw)	SRD	34	0	0		
G1	White Spruce (Sw)	HASOC (Canfor 50%, Weyer 50%)	139	135	4		
G2	White Spruce (Sw)	FGAA (MDFP, SRD, Tolko)	106	27	0		
H	White Spruce (Sw)	SRD	68	0	0		
I	White Spruce (Sw)	HASOC (ANC 6.6%, HWP 31%, MWFP 32.4%, Weyer 30%)	172	172	5		
F1	Interior Douglas Fir (Fdi)	SRD	39	0	0		
L1	Black Spruce (Sb)	HASOC (ANC, HWP, MWFP)	138	0	1		
L2	Black Spruce (Sb)	HASOC (Canfor 50%, Weyer 50%)	68	31	2		
L3	Black Spruce (Sb)	SRD	41	0	0		
?	Scots Pine	SRD			3	**29**	**Conifer**
Pb1	Balsam Poplar (Pb)	Al-Pac	520	NA	3		
Aw1	Trembling Aspen (Aw)	WBAC (Ainsworth, DMI, Weyer)	427	NA	27		
Aw2	Trembling Aspen (Aw)	WBAC (Ainsworth, DMI, Weyer)	498	NA	5	**35**	**Deciduous**
				711	**64**		

Table 3. CPP regions, seed collected, test sites measured.

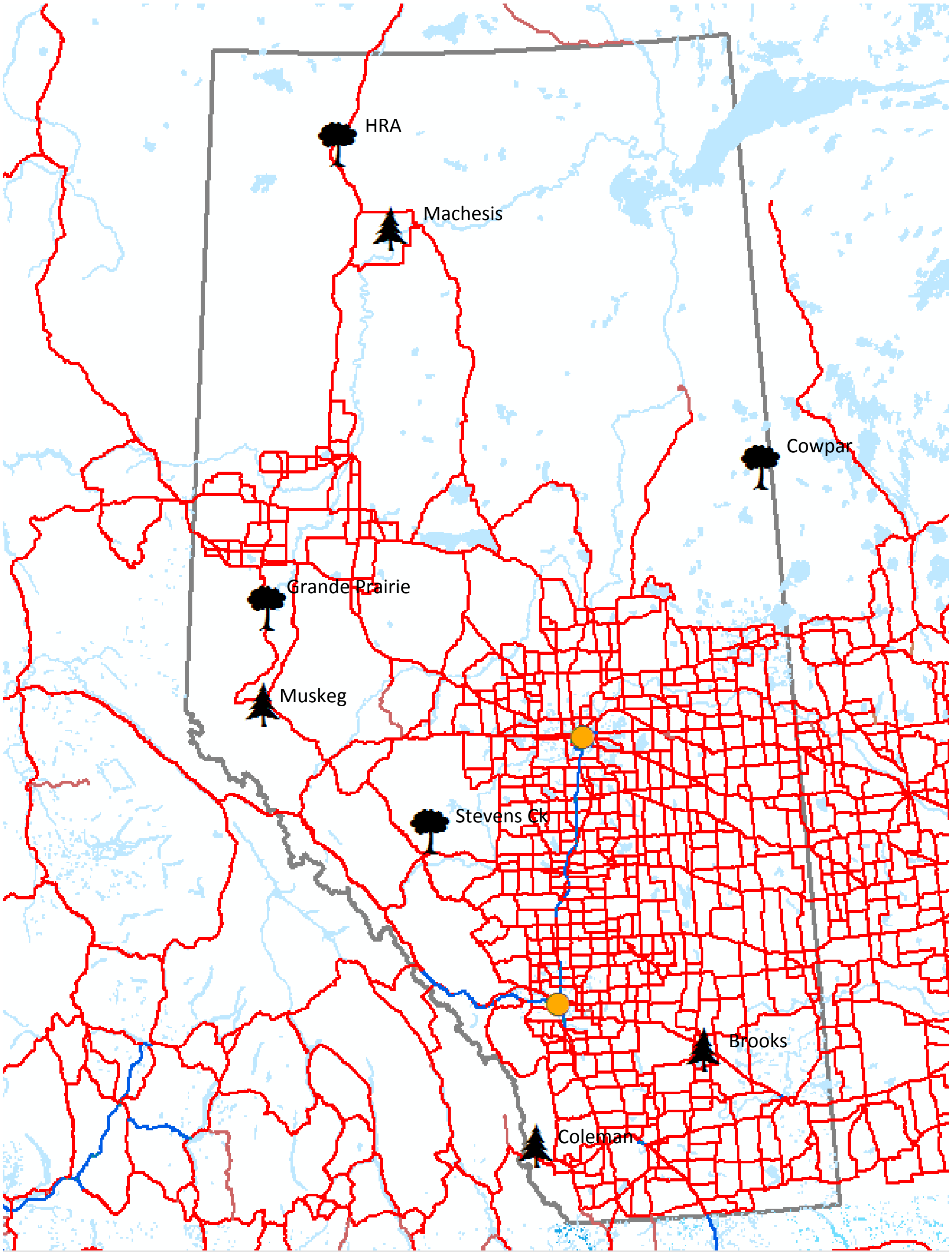

Figure 1. Adaptation test sites (coniferous and deciduous).

Climate Change Risk Assessment Reviews for all CPP Regions

A series of 24 reports were provided as an outcome of the CCEMC-funded TSARM Project (2012–2015), submitted by Deogratias Rweyongeza, Leonard Barnhardt, Barb Thomas, and Bruce Macmillan. Work completed by doctors Laura Gray and Andreas Hamann on the climate change projections for the province and each individual controlled parentage program (CPP) is presented in sections 1 and 2 of the compiled reports. (See Appendix 2: Climatic Adaptation of White Spruce and Lodgepole Pine in Alberta TSARM_ClimateAdapt_SwPl_2015Jul16.pdf and Appendix 3: Projected Changes in Climate for Alberta and Forest Tree Improvement Program Regions TSARM_ClimateModeling_2015Jul16.pdf).

Section 1 provides a series of projects from the current climate (1961–1990) through to the 2080s for the entire province (shown below). Section 2 (not shown below) provides a figure for each individual CPP region using 2,000 pixels from a one-kilometre grid of the CPP region (except for CPP region M with a maximum of 750 pixels available) and for the mean annual temperature (MAT) versus mean annual precipitation (MAP), including test site locations. Climate variables are based on the 1961–1990 "normal" climate period. Section 3 provides details (not shown below) on each specific CPP and consists of a template that was developed by a team working with the TSARM project and filled out by Sally John (conifer programs), Jean Brouard (aspen programs), and Barb Thomas (balsam poplar program). Many other individuals assisted with gathering the information to populate the templates, including, in particular, Leonard Barnhardt, Alberta Tree Improvement and Seed Centre manager (now retired), and Tammy De Costa, with Environment and Sustainable Resource Development, Forestry and Emergency Response Division, Government of Alberta, who completed much of the GIS work required for the conifer reviews.

The purpose of these reports was to provide CPP plan proponents with the results from various reports and documents as a single package. The intent was to give them the information they need to evaluate the risk of climate change and determine what steps, if any, need to be taken to ensure their program remains robust in light of projected climate change in their respective regions. Below is the general background and project rationale that was provided for each CPP review, which also included individual reports, as shown in Table 4.

Climate Summary Report for the Province and CPP Region

Background

(by D. Rweyongeza)

For over 200 years, genecological (Toresson 1923) studies have revealed a close relationship between plant populations and their environment, especially climate (Langlet 1971). Because temperature, heat, moisture, and these factors' spatial and seasonal variations exert direct pressure on plant survival, growth, and reproductive processes, plant species exist as a mosaic of genetically differentiated populations, each adapted to a local climate (Linhart and Grant 1996). This climatically induced natural selection is well established in forest tree species, especially those in temperate and boreal climates where spatial and seasonal temperature variations are the greatest (see Rweyongeza and Yang 2005; Davis et al. 2005; Loehle 1998).

In forestry, provenance studies involving planting climatically diverse populations at many sites with different climates have played a key role in formulating seed-use guidelines as well as in providing initial measures of the potential impact of climate change on forest productivity (Stettler and Bradshaw 1994; Matyas 1994). For example, in British Columbia and Alberta, such studies exist for lodgepole pine (Rehfeldt et al. 1999, 2001; Wang et al. 2006; Rweyongeza et al. 2007), white spruce (Rweyongeza et al. 2007; 2010; Rweyongeza 2011), and aspen (Gray et al. 2011), which are the most important commercial species in Alberta. Preliminary analyses of data from these provenance trial studies have led to short-term modifications of seed-transfer guidelines in British Columbia and Alberta as well as to identifying research gaps that must be addressed to better understand the challenges of adaptation to climate change.

In order to maintain healthy and productive forests, seed-transfer guidelines and policy must take into account climatically induced natural selection and the adaptation it produces in local populations. Since reforestation began in this province, climatic similarity between the seed source and reforestation site has been an indicator of the extent to which trees to be planted are considered adapted to the target planting site, including adaptation to biological agents such as insects and diseases, whose activities and genetics are also influenced by climate. Tree adaptation to local climates is a product of evolution over many generations spanning thousands of years. Therefore, rapid changes in climate occurring over decades will offset the equilibrium between tree biological processes and the environment, affecting the health and productivity of forests. To sustain healthy and productive forests in a rapidly changing climate, human intervention will be needed to select or develop adapted seed and clones for deployment as well as to identify and conserve natural populations with unique gene pools.

One of the primary tools in managing genetic resources in a changing climate is to identify the extent and direction of climate change for climatic variables of biological significance. Identifying these significant biological variables allows policy makers and forest managers to adjust tree-planting prescriptions to reduce the impact of climate change in the interim using natural populations and existing seed production facilities (e.g., seed orchards) while pursuing long-term adaptation measures through research. In 2012, the CCEMC funded the TSARM project. This project is being implemented jointly by TIA, which comprises both forest companies involved in tree improvement and Alberta Environment and Sustainable Resource Development (ESRD). Considerable in-kind funds have also been contributed by both industry and ESRD to ensure the project’s success.

The aim of the TSARM project is to generate data, science-based inferences, and recommendations that enable the Alberta government to adopt provincial policies that integrate climate change adaptation into seed and clonal transfer guidelines for reforestation on Crown land.

Research Rationale

Throughout Alberta, as in most forested landscapes, tree populations predominantly show clinal patterns of adaptation to different macroclimatic conditions (Rweyongeza et al. 2007; Rweyongeza et al. 2010). Therefore, to facilitate healthy and productive managed forests, reforestation programs in the province require planting stock that has sufficient genetic diversity and that is genetically well adapted to the target environment. Projected future changes in temperature and precipitation therefore create a challenge for the province's reforestation programs. Climate change effects on tree species will likely be ongoing, cumulative, and interactive, given that deviations from current climate conditions are projected to amplify over time. For example, trees that are stressed by changes in site conditions (e.g., moisture limitations) may become more susceptible to insects and diseases that in turn become more active due to projected warming temperatures. The many interactions and feedback patterns in the life cycle of a tree add to the complexity we can expect from climate change effects.

Over the last three decades, replicated provenance and progeny field trials have been used to relate tree characteristics such as growth and phenology to environmental characteristics (see Rweyongeza et al. 2010 for details). Further, these experiments have been used for extensive testing and selection of planting stock by the province's industry and government agencies to maintain tree improvement programs for white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta*), jack pine (*Pinus banksiana*), black spruce (*Picea mariana*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), balsam poplar (*Populus balsamifera*), and trembling aspen (*Populus tremuloides*). For each species program, seed (or cuttings) is collected from, and planting stock is developed for, different physiogeographic regions within Alberta, known collectively as CPP regions, which are specific to each species and region of the province.

Currently, provincial regulations direct that planting stock must be deployed within its region of origin to prevent lost productivity or poor forest health due to maladaptation. Tree species and genotypes may acclimatize or adapt to future climates; however, in many cases, the rate of climate change will likely significantly exceed the ability of tree species to adjust naturally. Therefore, the current seed-transfer strategy within the network of CPP regions may be problematic in the future, as climate change will likely cause a mismatch between the climatic conditions of the CPP region planting environment and those that the CPP region planting stock is adapted to.

To adequately assess the risks and challenges that future climates may present to tree improvement in Alberta, climate shifts at the level of the CPP regions must be identified. This report therefore summarizes and illustrates projected climate shifts over the province and, more importantly, at the level of the species-specific CPP regions.

Climate Trends and Projections

Baseline climate data for Alberta were derived from monthly temperature and precipitation grids that were generated by Daly et al. (2008) using the Parameter-elevation Regression of Independent Slopes Model (PRISM) to interpolate climate normal data observed at weather stations throughout the province for the period 1961–1990. This database was enhanced with lapse-rate-based down-sampling to one-kilometre resolution and estimation of biologically relevant variables (Hamann and Wang 2005;

Wang et al. 2006; Mbogga et al. 2009). For an overall climatic summary, 12 variables were selected to thoroughly illustrate climate change projected for the province. These variables include the following: 1) mean annual temperature, 2) mean coldest month temperature, 3) mean warmest month temperature, 4) continentality (difference between mean January and mean July temperature), 5) average winter temperature (December–February), 6) mean summer temperature (June–August), 7) growing degree days above 5°C, 8) frost-free period, 9) mean annual precipitation, 10) mean growing season precipitation (May–September), 11) annual climate moisture (dryness) index, and 12) summer (June–August) climate moisture index according to Hogg (1997). Hogg's (1997) dryness indices were selected over alternative methods as they include potential evapotranspiration within their calculation. For the independent species-specific CPP regions, six climate variables considered to be the best indicators of climate changes that may affect tree establishment and growth were selected for mapping. These variables include the following: 1) mean coldest month temperature, 2) mean warmest month temperature, 3) growing degree days above 5°C, 4) frost-free period, 5) mean growing season precipitation (May–September), and 6) summer (June–August) climate moisture (dryness) index according to Hogg (1997).

Climate projections for the province for the 2020s, 2050s, and 2080s were generated by overlaying projections from general circulation models, expressed as the difference from the 1961–1990 normal period. The recent Fifth Assessment Report from the Intergovernmental Panel on Climate Change illustrates that the current global emission outputs most closely resemble the projected emission outputs for the pessimistic A1B SRES emission and population growth scenario (*Climate Change 2013: The Physical Science Basis*, Cambridge University Press, Cambridge, U.K., 2014). Therefore, for this summary report, future projections were based on an ensemble of outputs from seven modelling groups (CCCMA_CGCM3, Canada; CSIRO_MK3, Australia; IPSL_CM4, France; MIROC3_2_HIRES, Japan; MPI_ECHAM5, Europe; NCAR_CCSM3, United States, and UKMO_HADGEM1, United Kingdom) each implementing the A1B SRES emission and population growth scenario for each future period. All current and future projections were generated using the freely available ClimateWNA software, version 4.71 (Wang et al. 2012).

Projected Climate Shifts: Alberta

Maps illustrating the shift in each of the climate variables summarized in this report over Alberta are provided in Figures 2–14, with Figures 2–7 representing changes in general temperature variables, Figures 8–9 representing changes in growing degree days and frost variables, Figures 10–11 representing changes in precipitation and Figures 12–13 representing changes in climate moisture.

In general, future projections suggest an overall annual warming throughout the province, beginning in the 2020s and accelerating towards the 2080s (Figure 2). However, by comparing the warming trends in both the winter (Figures 3 and 6) and summer (Figures 4 and 7) seasons, it is evident that the warming signal is projected to be stronger in the colder months, particularly in the northern mixedwood region of the province (Figures 3 and 6). This warming signal is further supported by a continual decrease in continentality in the northern mixedwood region, beginning in the 2020s and becoming more prominent in the 2080s (Figure 5).

A steady increase in growing-degree days above 5°C (Figure 8) suggests that the growing season for tree species may be extended in the future. This trend appears most noticeable in the parkland and northern dry mixedwood and central mixedwood regions. In addition, there is a projected increase in the frost-free period over the province, which, in the high-elevation upper boreal highlands and boreal subarctic regions, approximates a 30-day increase by the 2020s and approximately 50–60 days by the 2050s (Figure 9). These projections suggest that the occurrence of frost events may be reduced in the future, which could be beneficial for forest productivity.

In addition, future projections suggest a moderate increase in mean annual precipitation (Figure 9) and a more prominent increase in growing-season precipitation (Figure 11) extending from the foothills ecosystems, which follow the eastern slope of the Rocky Mountains, east along the polar jet stream storm track that defines the climatology of the boreal plains region (Alberta Environment 2005). This trend would result in more summer precipitation in the lower foothills, parkland, and southern dry mixedwood ecosystem regions of the province, where the latter two regions are characteristically drier ecosystems.

While these precipitation increases appear to be beneficial for tree growth, the annual (Figure 11) and summer (Figure 13) dryness indices indicate a reduction in moisture in these same regions. This dryness trend is likely the product of an increase in summer temperatures (Figure 7) exceeding the increase in precipitation (Figure 11), resulting in greater potential evapotranspiration and less moisture availability. This dryness trend could counter the expected benefits of increased precipitation on tree growth, and potentially result in greater drought events.

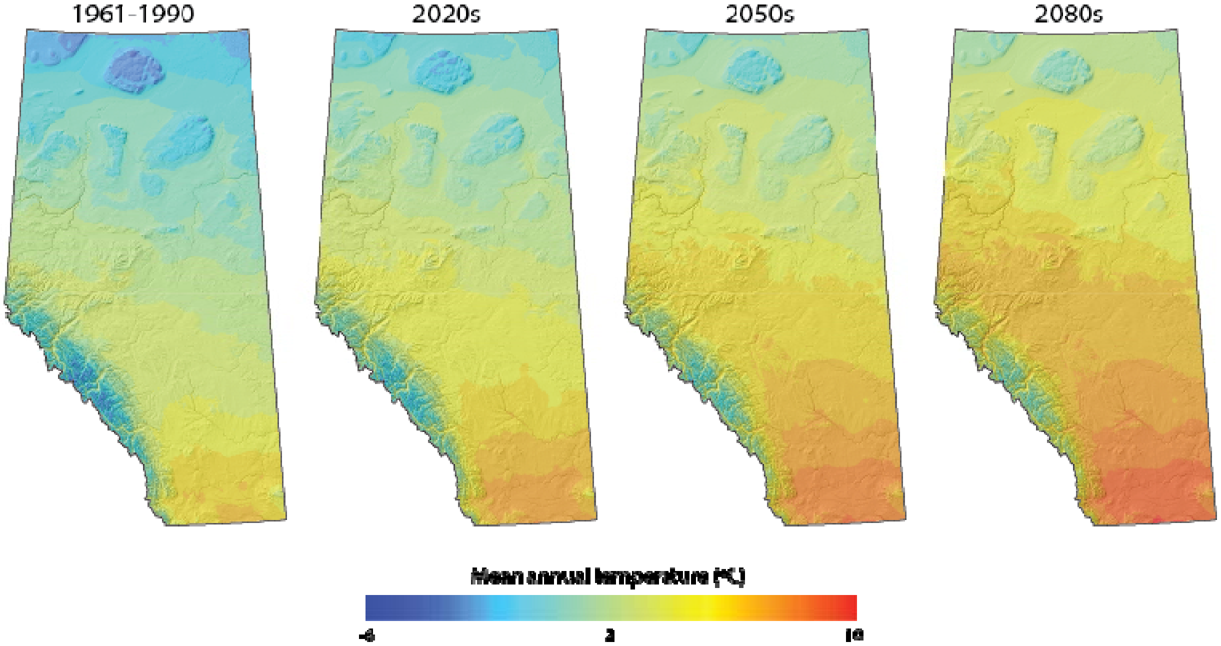

Figure 2. Current and projected future mean annual temperature for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

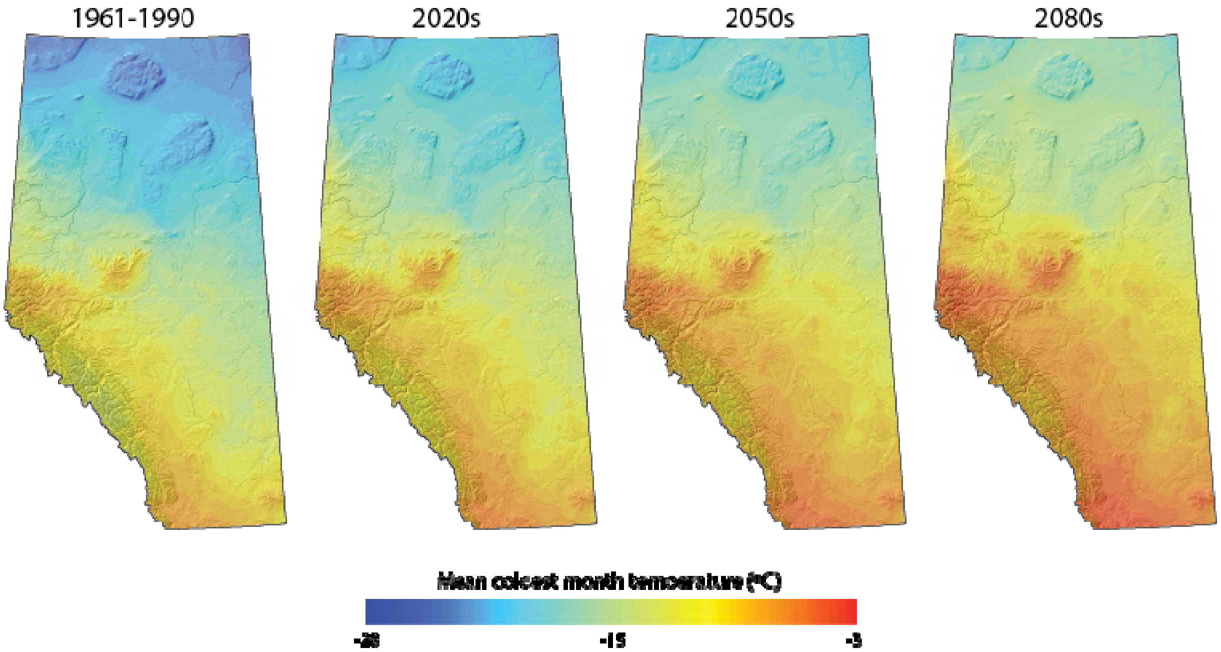

Figure 3. Current and projected future mean coldest month temperature for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

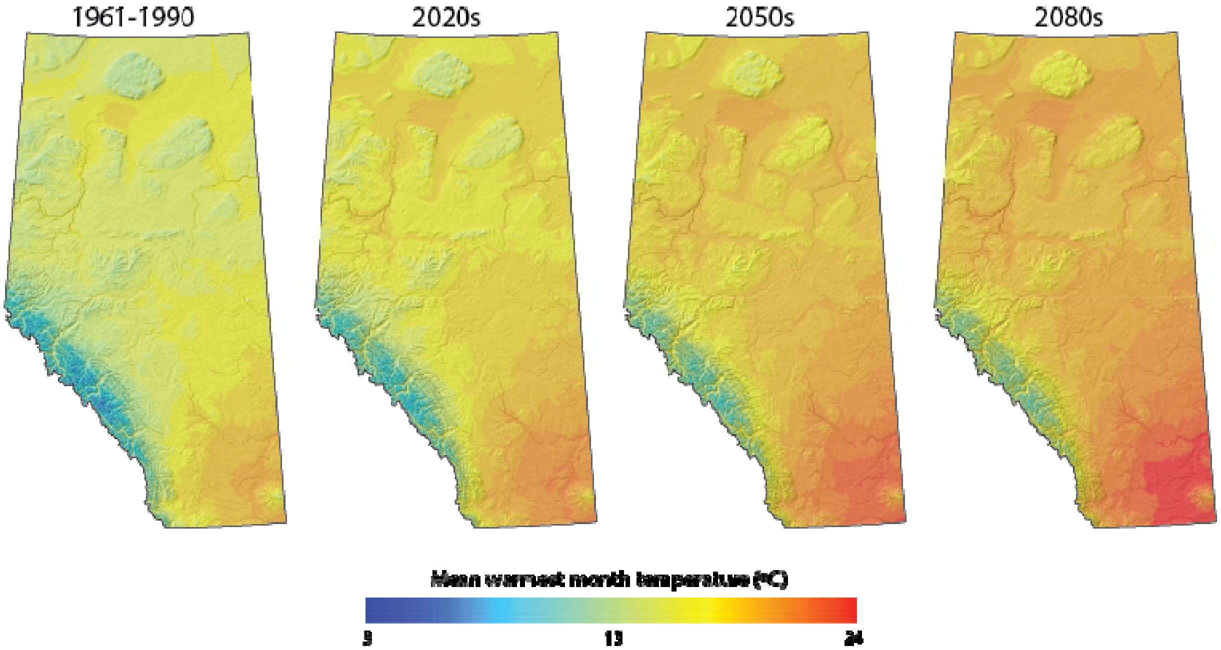

Figure 4. Current and projected future mean warmest month temperature for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

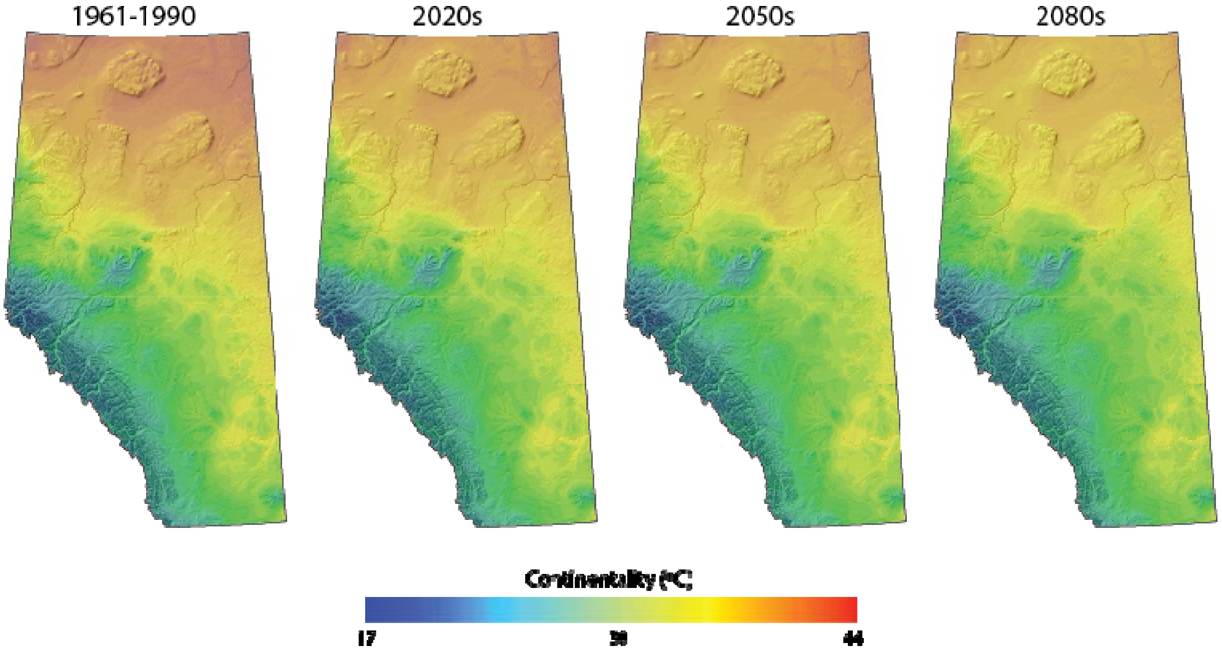

Figure 5. Current and projected future continentality (difference between mean January and mean July temperature) for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

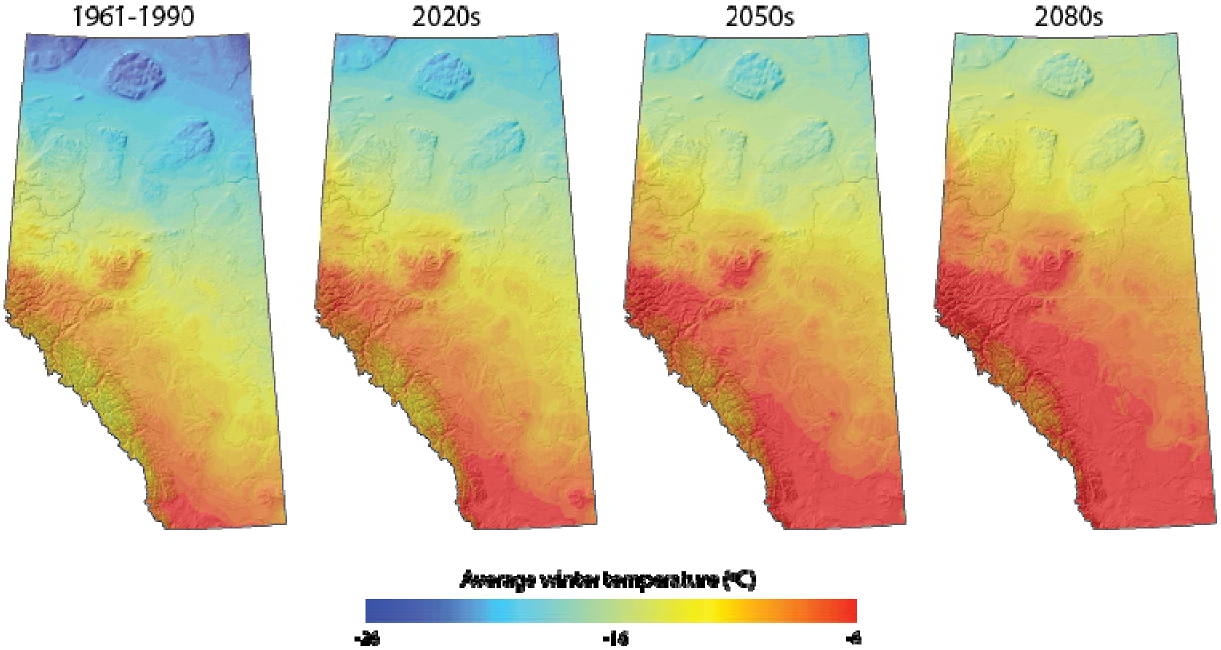

Figure 6. Current and projected future mean winter (December–February) temperature for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

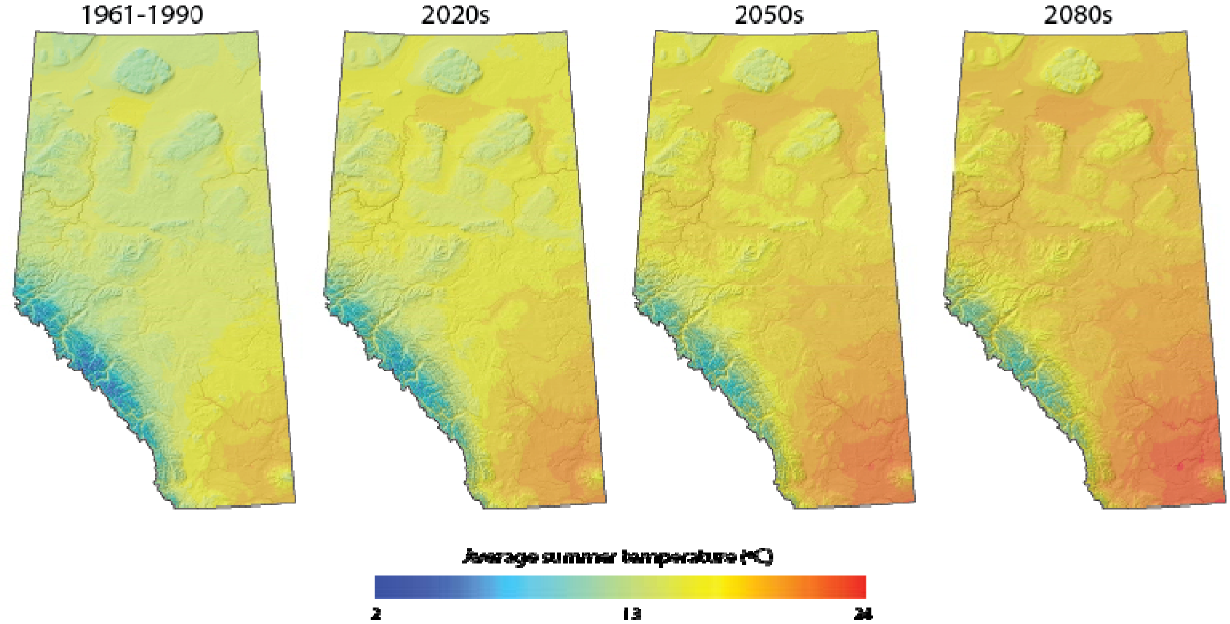

Figure 7. Current and projected future mean summer (June–August) temperature for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

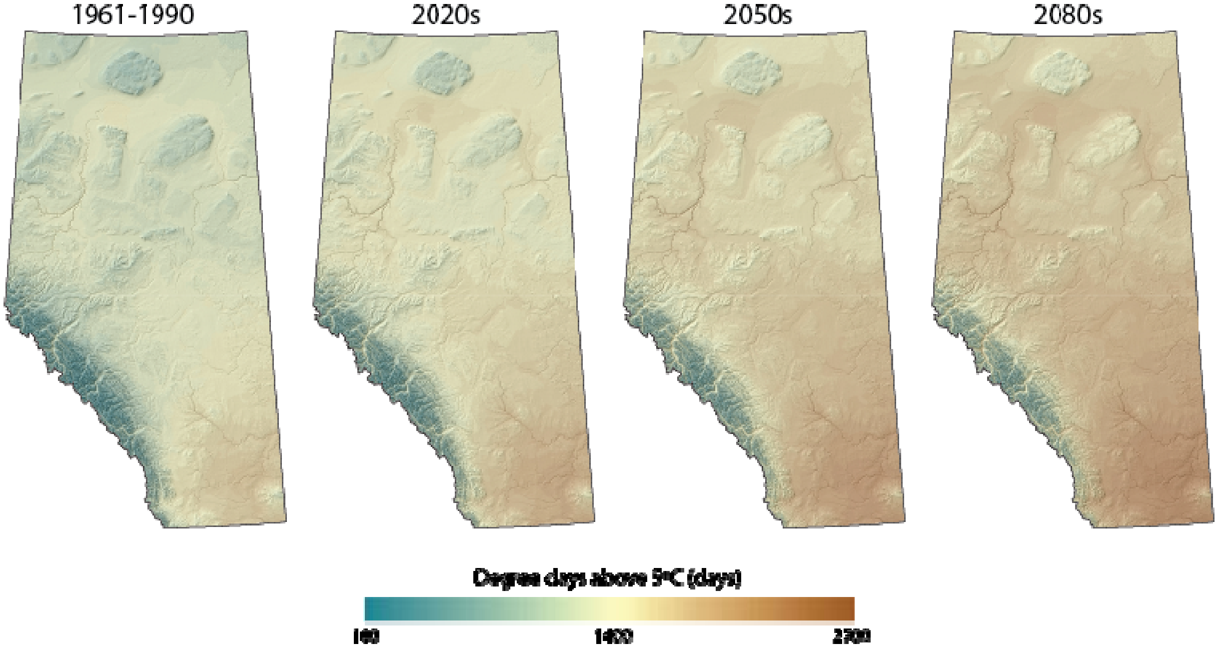

Figure 8. Current and projected future growing degree days above 5°C for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

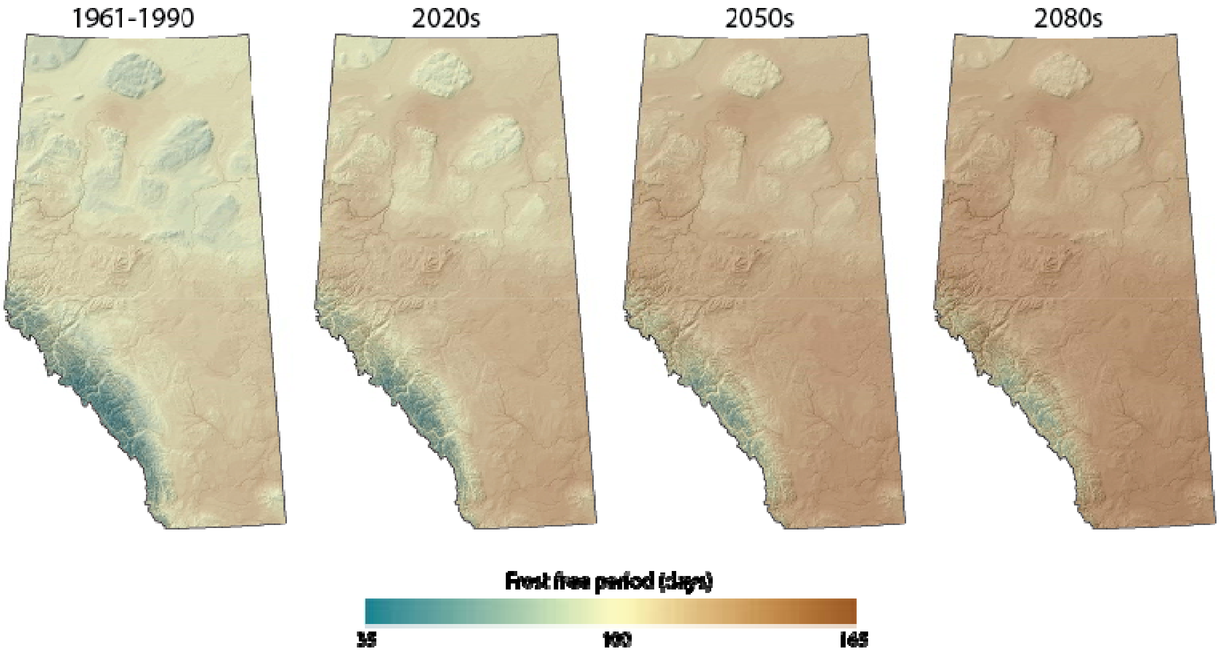

Figure 9. Current and projected future frost-free period for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

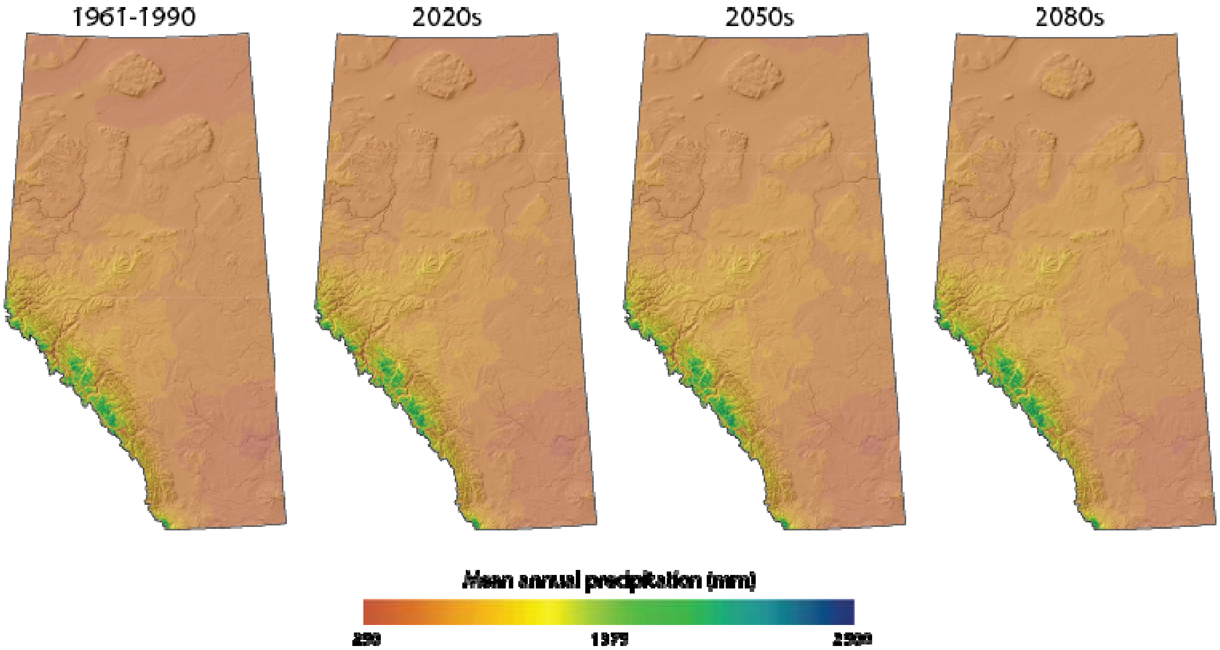

Figure 10. Current and projected mean annual precipitation for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

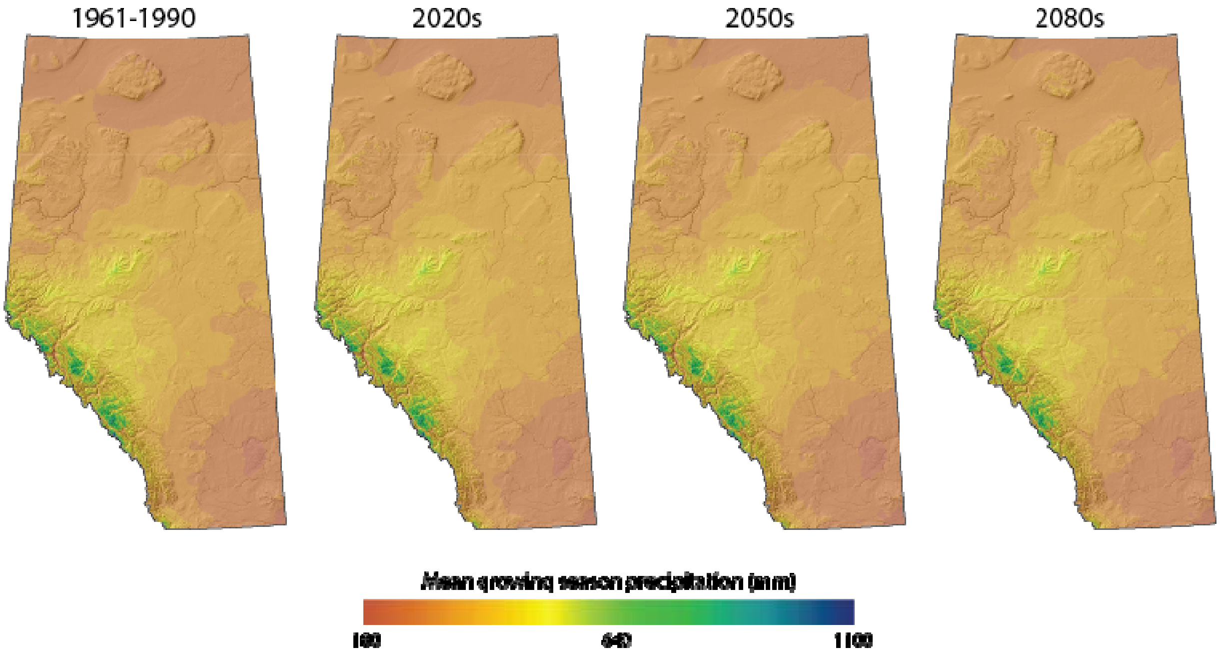

Figure 11. Current and projected mean growing season (May–September) precipitation for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

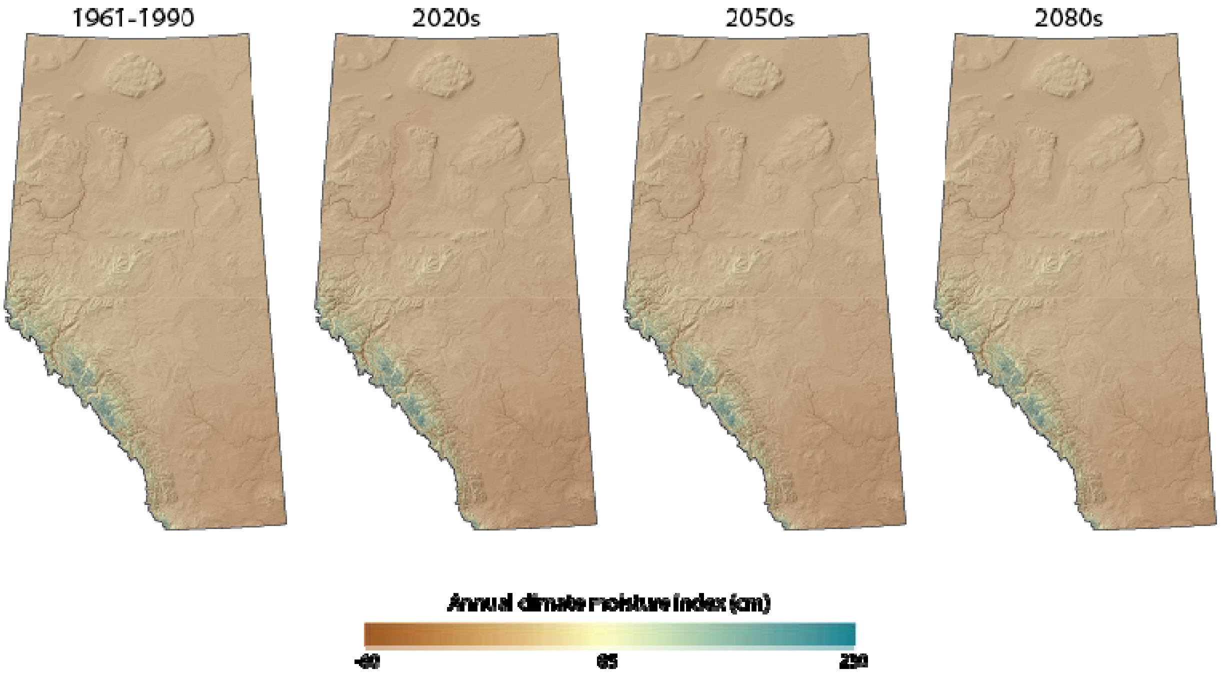

Figure 12. Current and projected annual climate moisture index for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

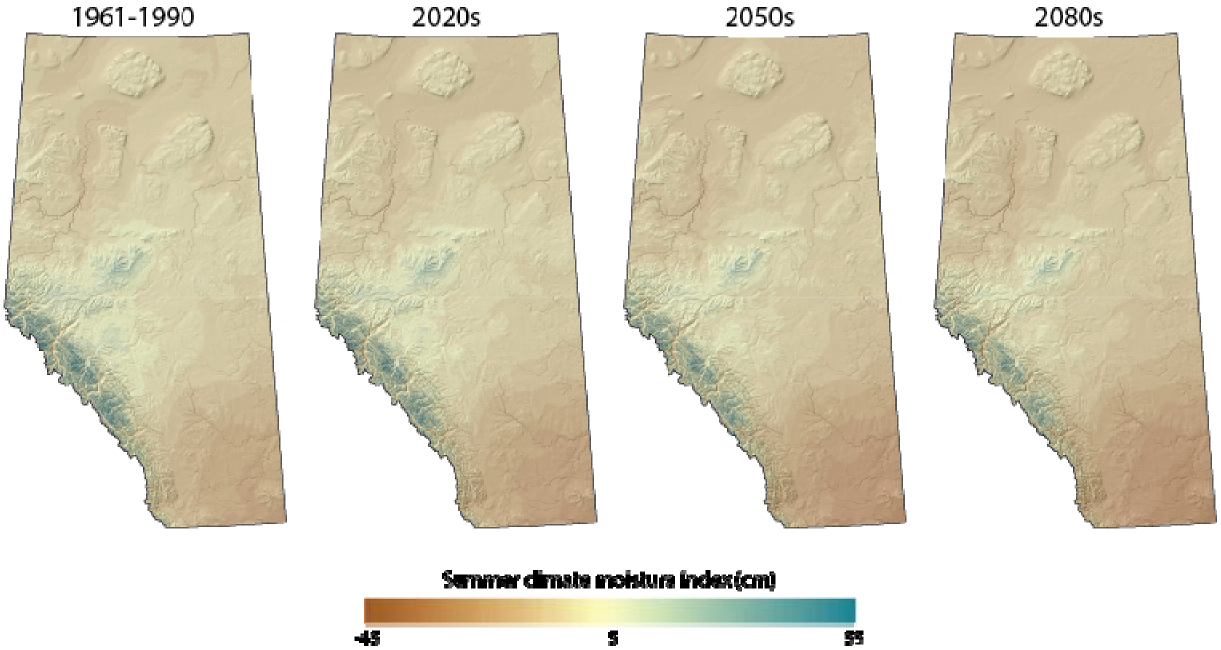

Figure 13. Current and projected summer (June–August) climate moisture index for Alberta. Future projections illustrate an ensemble of outputs from seven modelling groups implementing the A1B emission and population growth scenario.

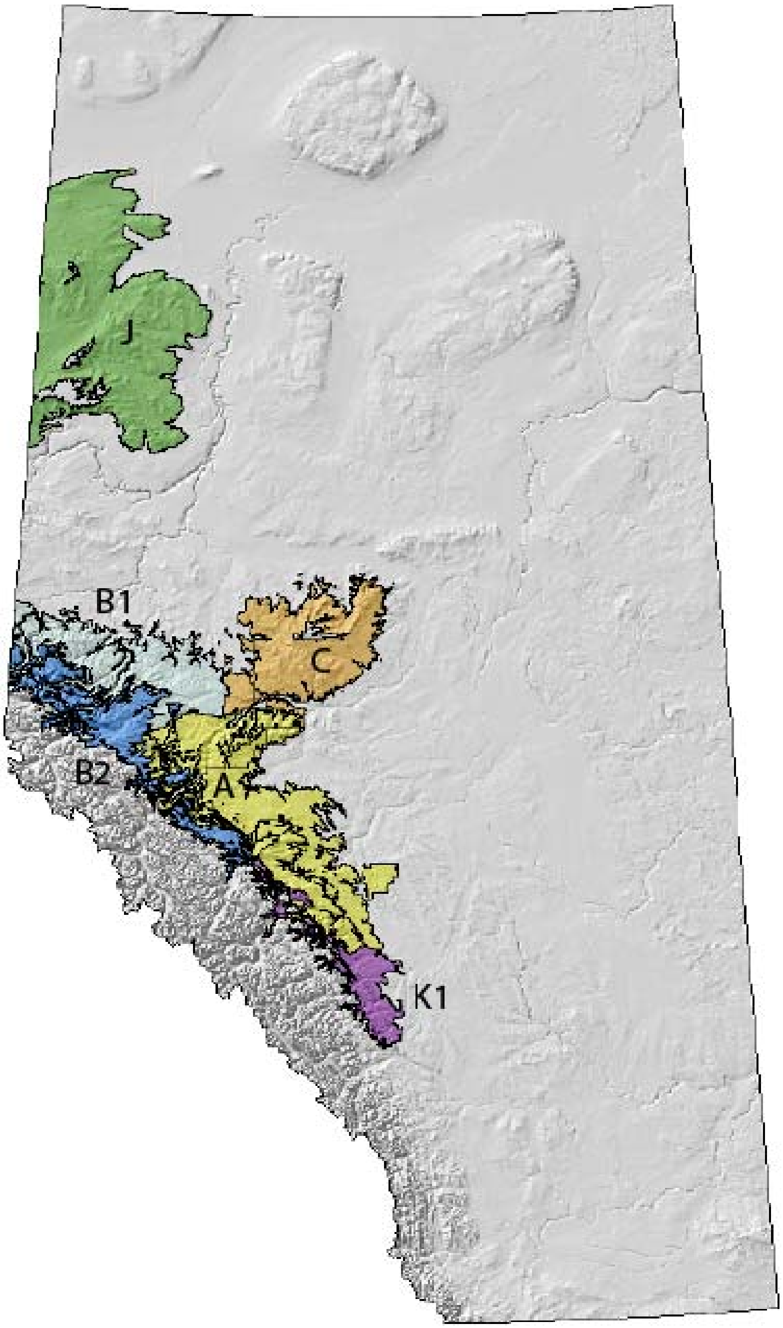

Figure 14. The six regions of the lodgepole pine (*Pinus contorta*) CPP.

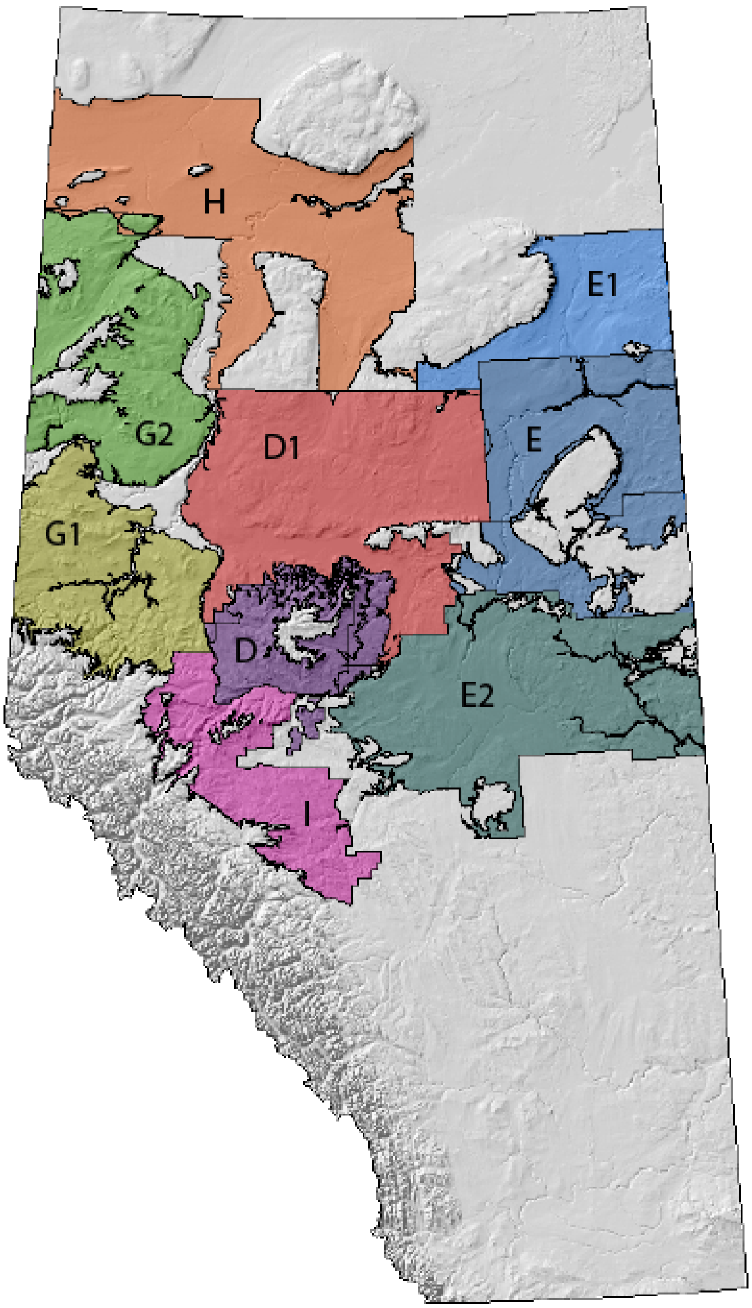

Figure 15. The nine regions of the white spruce (*Picea glauca*) CPP.

Region	Species	Title Page (Word File)	Intro Section (Word File)	MAT vs. MAP Figure (pdf File)	CPP Review Template (Excel File)	Converted to PDFs	Proponents
Region A	Pl	Done	Done	Done	Done	Done	West Fraser (HWP)
Region B1	Pl	Done	Done	Done	Done	Done	HASOC (ANC, Canfor, Weyer GP)
Region B2	Pl	Done	Done	Done	Done	Done	HASOC (HWP, Weyer GP)
Region C	Pl	Done	Done	Done	Done	Done	West Fraser (BRL)
Region J	Pl	Done	Done	Done	Done	Done	FGAA (MDFP, ESRD. Tolko)
Region K1	Pl	Done	Done	Done	Done	Done	ESRD & West Fraser (Sundre)
Region D	Sw	Done	Done	Done	Done	Done	West Fraser (BRL)
Region D1	Sw	Done	Done	Done	Done	Done	ESRD
Region E	Sw	Done	Done	Done	Done	Done	ESRD
Region E1	Sw	Done	Done	Done	Done	Done	FGAA (Northlands, ESRD)
Region E2	Sw	Done	Done	Done	Done	Done	ESRD
Region G1	Sw	Done	Done	Done	Done	Done	HASOC (Canfor, Weyer GP)
Region G2	Sw	Done	Done	Done	Done	Done	FGAA (MDFP, ESRD, Tolko)
Region H	Sw	Done	Done	Done	Done	Done	ESRD
Region I	Sw	Done	Done	Done	Done	Done	HASOC (ANC, HWP, MWFP, Weyer)
Region L1	Sb	Done	Done	Done	Done	Done	HASOC (ANC, HWP, MWFP)
Region L2	Sb	Done	Done	Done	Done	Done	HASOC (Canfor, Weyer GP)
Region L3	Sb	Done	Done	Done	Done	Done	ESRD
Region F1	Fd	Done	Done	Done	Done	Done	ESRD
Region M	Lw	Done	Done	Done	Done	Done	ESRD
Region P1	Pj	Done	Done	Done	Done	Done	FGAA (Northlands, ESRD)
Region Aw1	Aw	Done	Done	Done	Done	Done	WBAC (Ainsworth, DMI, Weyer P)
Region Aw2	Aw	Done	Done	Done	Done	Done	WBAC (Ainsworth, DMI, Weyer P)
Region Pb1	Pb	Done	Done	Done	Done	Done	Al-Pac

Table 4. List of CPP regions, species, components, and proponents.[2]

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[2] HWP = Hinton Wood Products; ANC = Alberta Newsprint Company; Canfor = Canadian Forest Products; Weyer GP = Weyerhaeuser Company, Grande Prairie Division; HASOC = Huallen Seed Orchard Company; BRL = Blue Ridge Lumber; FGAA = Forest Genetics Alberta Association; MDFP = Manning Diversified Forest Products; ESRD = Environment and Sustainable Resource Development (now called Agriculture and Forestry); MWFP = Millar Western Forest Products; DMI = Daishowa Marubeni; Weyer P = Weyerhaeuser Company Pembina Division; Al-Pac = Alberta-Pacific Forest Products.

Education and Extension Activities

The CCEMC and TIA hosted a variety of business meetings, workshops, and field trips during the development and implementation of the project.

A meeting was held by TIA on January 16, 2012, in Edmonton, to complete the final steps for receiving funding from the CCEMC. The TIA agreement between proponents was finalized, and the proponents provided seed money to hire a project manager. TIA needed to sign an agreement with Foothills Research Institute (fRI) to manage funds and process invoicing for the project.

The inaugural meeting of TIA was held June 7, 2012, in Edmonton. During this meeting, the TIA terms of reference were reviewed and information on board members and the joint steering committee with the CCEMC was provided. This meeting also addressed timelines and workplans for conifer and deciduous trees, and the payment process for the three-year CCEMC project was discussed.

Stakeholder Workshop #1

The first CCEMC/TIA stakeholder workshop was held February 5, 2013, in Edmonton, with all participants in the TSARM project and representatives of academia (University of Alberta and University of Regina), ESRD, and industry. There were 38 participants and seven presenters.

The key guest speaker was Dr. Norman Henderson, director, Prairie Adaptation Research Collaborative, University of Regina. Dr. Henderson spoke on interventional forest management in Britain and how we should consider climatic hardy populations of native species before importing exotics for climate change adaptation.

An update on provenance trials and climate change was provided by Deogratias Rweyongeza, ESRD, AAF. Dr. Laura Gray provided an overview of the workplan being developed for climate change modelling, and Dr. Ken Greenway provided an update on a fact-finding trip to learn how B.C. has structured tree improvement programs. Dr. Barb Thomas gave an update, and Bruce Macmillan led a round-table discussion on project priorities.

Figure 16. TIA/CCEMC workshop, February 5, 2013.

Field Tour #1 to Provenance and Progeny Trials

A two-day field tour was held at Drayton Valley and Rocky Mountain House April 23 and 24, 2013, to visit select provenance and progeny trials for both coniferous and deciduous trees. The field tour was well attended, with over 30 participants from industry, Alberta Innovates Bio Solutions, Alberta Innovates Technology Futures, and ESRD. Participants visited a western boreal aspen provenance trial at Medicine Lake. Jean Brouard provided information on provenance and noted that trees migrating north had the best survival. The remaining sites, hosted by industry and ESRD, focused on lodgepole pine, jack pine, Douglas-fir, white spruce, and hybrids at Diamond Hills and Tershishner Creek. Progeny trials at Clearwater and Dry Creek, as well as survival and growth of the species, were discussed at each site. Future effects of climate change were also discussed.

Figure 17. Medicine Lake.

Figure 18. Jean Brouard at Medicine Lake.

Figure 19. Diamond Hills.

Stakeholder Business Meeting and Workshops

The second CCEMC/TIA stakeholder workshop took place on January 15, 2014, in Edmonton. A business meeting was held for TIA members the evening of January 14, 2014.

Stakeholder Business Meeting #1

The business meeting was attended by 22 members, and there were eight presenters. Topics included:

- History of TIA by Shane Sadoway, West Fraser (WF), TIA board of directors
- Costing pricing model and update on government tree improvement direction by Leonard Barnhardt and Andy Benowicz, ESRD
- Update on merger of growth and yield associations by Terry Kristoff, WF
- FRIAA updates for conifer and deciduous funding by Shane Sadoway and Dr. Barb Thomas, ALPAC
- Project and future funding opportunities by Deogratias Rweyongeza, ESRD

This meeting segued into a brainstorming session led by Barb Thomas, in which members identified the projects TIA should focus on.

Stakeholder Workshop #2

There were 44 participants with 11 presenters for the 2014 workshop, which was attended by all participants in the TSARM project and representatives of academia (University of Alberta and University of Regina), ESRD, and industry. The morning focused on presentations that provided updates on CCEMC/TIA projects and climate change research.

Dr. Sally John and Dr. Laura Gray provided updates on conifer tree improvement programs and a climate change analysis project. An overview of CCEMC climate change mitigation and adaptation initiatives was presented by Ray Luchkow, CCEMC. Greg O'Neil, B.C. Ministry of Forests, provided information on climate change impacts, and David Price, Canadian Forest Service, spoke about assisted climate change in B.C. and gave a national-level climate change overview.

The afternoon session featured a presentation on deployment of improved seed by Diane Renaud, West Fraser. Leonard Barnhardt, ESRD, provided updates on government initiatives and the Genetics Council.

Field Tour #2 to Aspen Trials and Conifer Tree Orchards

A second field tour of Grovedale aspen trials and Huallen conifer tree orchards was hosted by CCEMC and TIA.

The Western Boreal Aspen Corporation (WBAC) is a not-for-profit corporation established in 1992. Its mission is to develop genetically improved aspen and to support research toward achieving successful deployment to meet the fibre needs of its member companies. Its secondary focus is addressing poplar tree improvement. The Grovedale site was moderated by Jean Brouard, WBAC geneticist. Information was provided on height, diameter and volume growth for aspen planted from different geographic locations.

The Huallen Seed Orchard Company (HASOC) is a cooperative of five companies—ANC Timber Ltd., Canadian Forest Products Ltd., Hinton Wood Products (a division of West Fraser Mills Ltd.), Millar Western Forest Products Ltd., and Weyerhaeuser Company Ltd. (Grande Prairie and Pembina divisions). Its purpose is to realize genetic gain, provide high-quality material for reforestation, and maintain genetic diversity and long-term genetic adaptive capability. Sally John, HASOC geneticist, provided the history on the orchards and ongoing management at Huallen.

Richard Reich, pathologist, provided a handout on diseases, conducted a tour showing samples of needle blight and some rusts at the Huallen site, and discussed how climate change could increase diseases. Ward Strong, entomologist, discussed insects and challenges that climate change could create for insect migration.

Laura Gray spoke about the climate change challenges on controlled parentage plans (CPPs) and provided a handout with valuable information on the current state of CPPs.

Stakeholder Business Meeting #2

TIA held a business meeting on January 13, 2015, to review workplans and project deliverables, ensure that all activities were on track for completion, and bring members (industry and government) up to date on progress and findings. The business meeting was attended by 20 members and featured nine presenters. Topics included:

- Overview of TIA and update on the CCEMC workplan
- Update on the improved material directive from Darren Tapp, ESRD
- Seed costing update from Andy Benowicz
- Update on Forest Genetic Resource Management and Conservation Standards from Deogratias Rweyongeza, ESRD/TIA
- Growth and yield merger update by Terry Kristoff, WF

Dr. Barb Thomas reviewed the compiled 2014 brainstorming actions and who was identified to action them.

Stakeholder Workshop #3

On January 14, 2015, TIA held a stakeholder workshop attended by all participants in the TSARM project and representatives of academia (University of Alberta and NAIT), research institutions (Canadian Forest Service, Alberta Biodiversity Monitoring Institute, and fRI), the energy sector, CCEMC, Alberta Innovates, and ESRD. The workshop included invited speakers from the University of British Columbia. There were 48 participants with 14 presenters, and the focus was on TIA climate change initiatives and related climate change research.

Ian MacLachlan, AdapTree, spoke about the effects of selective breeding on climate-related traits of spruce in Western Canada. Tod Ramsfield, Canadian Forest Service, spoke about climate change and forest pathogens, and Kevin Jones and Janice Cooke from the University of Alberta presented on social acceptance of assisted migration and the interplay of climate change and mountain pine beetle genetics.

Dr. Laura Gray presented an update on her analysis and research on how climate change may impact the deployment of existing tree improvement programs for pine, white spruce, and black spruce. Dr. Barb Thomas introduced the mass propagation of trembling aspen project, and Larry Lafleur presented handouts on Smoky Lake Forest Nursery's experience with mass propagation of aspen using stacked styroblocks. Cornelia Kreplin, Alberta Innovates Bio Solutions, delivered an overview of current funding initiatives, and Ray Luchkow, CCEMC, provided an overview of climate change mitigation and adaptation initiatives.

Todd Ramsfield, Canadian Forest Service, spoke about diseases and climate change. Darren Aitken, ESRD, talked about growth and yield, and genetic gain issues and challenges. Progress on all components of the TSARM project was presented and discussed, as were other topics relevant to tree improvement practitioners.

Stakeholder workshops have a direct and immediate impact on provincial policies on climate change adaptation.

Genetic Field Testing – Summary Report

The Alberta government and forest companies have been doing field genetic testing to determine species, population, and family seed-transfer limits in order to manage genetic adaptation in seed transfer for approximately 35 years. Information from these trials has allowed the development of geographic and, more recently, climatic species- and population-transfer functions to drive reforestation seed movement policy and adaptation to climate change.

Projections suggest that, in a changing climate, Alberta will become increasingly drier as increases in heat outpace annual precipitation. In addition, projections suggest that increases in temperature will allow tree populations to be moved further into areas that were previously cooler than their optimal environment for survival, growth, and reproduction. This presents 1) a challenge to forest regeneration, health, and productivity due to drought, and 2) an opportunity to increase productivity in northern Alberta and in mountainous areas where annual growth is currently limited to populations adapted to a shorter and cooler growing season.

The current Alberta Forest Genetic Resource Management and Conservation Standards (FGRMS 2009)[3] regulate the collection, propagation, and deployment of seed and cuttings on public land with the intent of preventing loss in productivity and forest health due to inappropriate material transfers. To reduce potential regeneration failure and decline in forest health and productivity in "central Alberta" while seizing an opportunity to increase productivity in the north and mountainous areas, the current FGRMS (2009) deployment standards will have to be revised to address tolerance to drought in summer and occasional extreme cold weather in winter.

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[3] Alberta Forest Genetic Resource Management and Conservation Standards (FGRMS). 2009. Publication No. Ref. T/213. Edmonton, AB. http://esrd.alberta.ca/lands-forests/forest-management/forest-management-manuals-guidelines.aspx.

In years two and three, the project worked on developing three coniferous test sites (central parkland, northern dry mixedwood, and northern subalpine). These sites have been cleared, access developed, site prepared, and fenced. A fourth coniferous site (southern subalpine) has been located and surveyed for suitability for field experimentation, and consultation with local authorities and land users to secure access has been completed. Four additional test sites have been located and surveyed through the CCEMC project for deciduous testing. These new deciduous sites will also contribute new information and assist with FGRMS revisions in the future. See Table 5 and Figure 1 for adaptation test site locations.

In addition to the four coniferous and four deciduous adaptation test sites under the CCEMC project, Environment and Sustainable Resource Development (ESRD) and its industrial cooperators have expanded the lodgepole pine (Region J; two sites) and white spruce (Region E1; six sites) programs to include many tree populations and families from outside the target planting areas as part of their climate change adaptation testing. The Region J and E1 sites are being planted over three years (spring 2014 through 2016). Testing on all of these sites will provide ESRD with the data needed for evidence-based revisions to the FGRMS to address climate change adaptation in reforestation and reclamation reproductive material (seed and clones). Revisions to the current FGRMS (2009) are under way and will be finalized in the fall of 2015.

Adaptation Test Site Name	**Broad Species Group**	**Natural Subregion**	**Region of Alberta**
Machesis	Coniferous	Northern Dry Mixedwood	Northern AB (near Machesis Lake)
Muskeg	Coniferous	Northern Subalpine	Eastern Slopes (near Grande Cache)
Coleman	Coniferous	Southern Subalpine	Eastern Slopes (near Blairmore)
Brooks	Coniferous	Central Parkland	Southern AB (near Brooks)
Hay River Area (HRA)	Deciduous	Central Mixedwood	Northern AB (near Meander River)
Cowpar	Deciduous	Central Mixedwood	Northeastern AB (near Athabasca)
Grande Prairie	Deciduous	Central Mixedwood	Northwestern AB (near Grande Prairie)
Stevens Creek	Deciduous	Lower Foothills	Foothills of West Central AB (near Rocky Mountain House)

Table 5. Adaptation test sites.

Commercially Viable Aspen Mass Propagation Technology Development and Economic Analysis

This was a three-year project (July 2012–March 2015), designed to test several protocols for the mass production of trembling aspen (*Populus tremuloides* Michx.) on a semi-operational basis at three commercial nurseries in Alberta. Trembling aspen has an extremely wide range across North America (Figure 20) and is an important commercial species for use in pulp, oriented strand board, and various specialty markets.

In Alberta, two tree improvement programs have been developed and await government approval—the AW1 and AW2 controlled parentage programs (CPPs). The regions encompassed by these CPPs are shown in Figure 21, with AW1 in the northwestern region of the province and AW2 located to the south.

The desire to select superior individuals and “clone” them for operational deployment has been a bottleneck in advancing current aspen programs. With new clonal standards for deployment coming out in the fall of 2015, expanded use of fast-growing clones will be enabled.

The primary project (Project I) used plant material from two CPP regions for trembling aspen (AW1 and AW2). The AW1 CPP is managed by Daishowa-Marubeni International Ltd. near Peace River, while the AW2 CPP is managed by Ainsworth Lumber, now Norbord, near Grande Prairie, and Weyerhaeuser Company Pembina division near Drayton Valley (Figure 21). Project II is a more detailed study on the stacked block technique (Figure 22) and used 11 clones of aspen from the AW2 program that were already at the nursery facility.

In order to meet genetic diversity standards for operational deployment (effective population size (Ne)=18), a total of 30 clones were selected from each program, the intent being that the minimum number of clones needed would be achievable. Furthermore, each nursery was tasked with conducting an economic analysis of its methodology with the goal of producing a \$0.50–\$0.60 plantable tree. Furthermore, targets for production (~3,700 trees per clone (18)) were set to allow for a follow-up outplanting study testing clonal-block versus mixed-block plantings of aspen on new deciduous test sites, selected as another component of the overall project funded by the CCEMC.

Figure 20. The distribution of trembling aspen across North America.

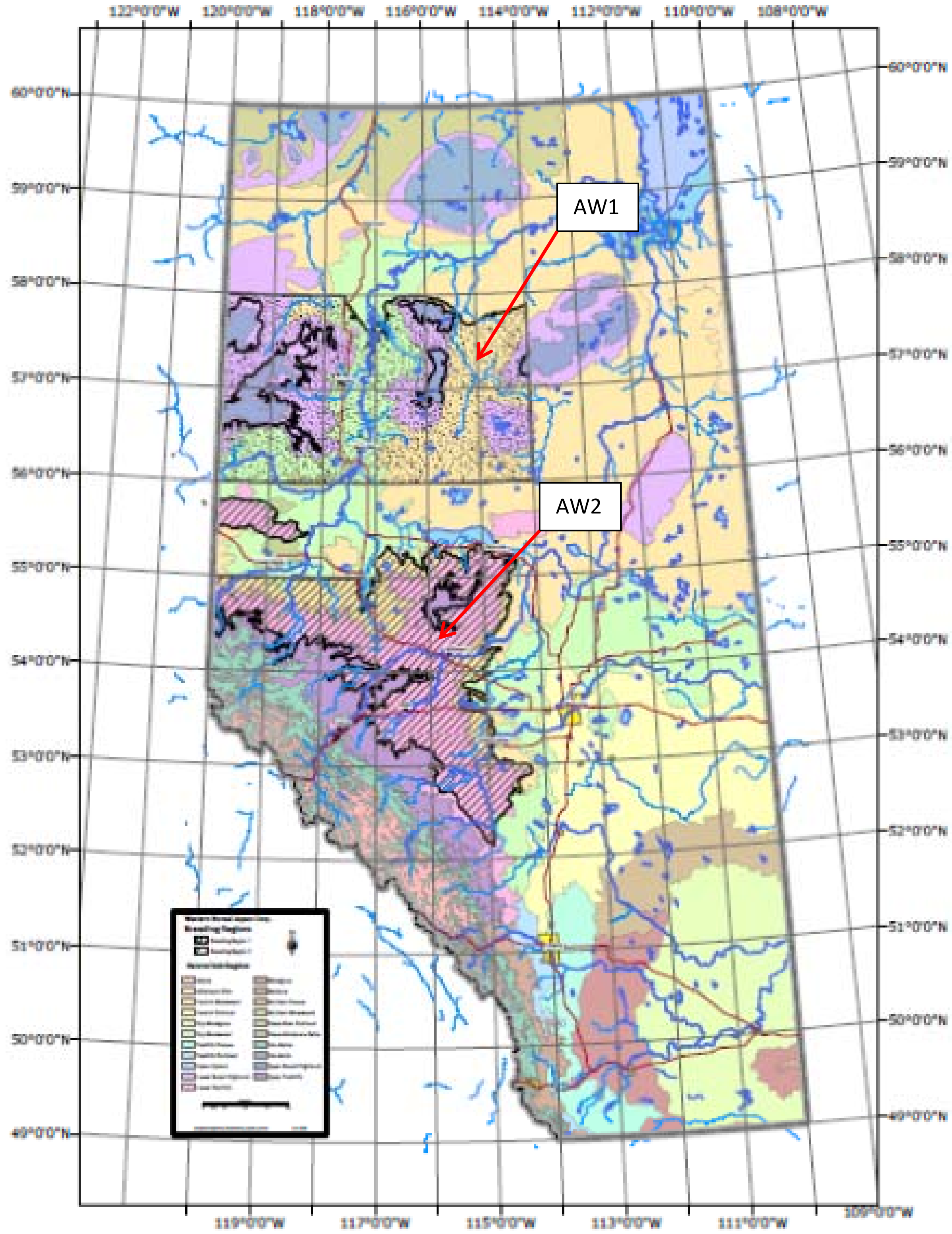

Figure 21. Delineation of the trembling aspen programs in Alberta, AW1 and AW2.

Figure 22. Aspen being propagated at Smoky Lake Forest Nursery using the stacked styro-block method.

Figure 23. Aspen being propagated at Woodmere Forest Nursery: a) Hydroponics, b) Roots prior to cold storage after hydroponic growth, c) Roots being processed for planting, d) Young planting.

Outcomes

Project I

Woodmere Nursery

Woodmere Nursery worked with 30 clones over the course of three years. In year one and year two, 15 clones were provided each spring for initial propagation. The first phase was to develop rooted cuttings to then produce a large root mass for steckling propagation via hydroponic root development (Figure 23).

Considerable challenges were encountered with the greenhouse conditions, including heat and spider mites resulting in relatively low production of rooted cuttings in the first phase. In the second phase, approximately 50% survival of root cuttings resulting in full plants was achieved. As is typical with aspen suckering and rooting, there was also considerable clonal variability in performance. This characteristic appears to be consistent regardless of propagation method and therefore requires considerably more clones to be screened prior to selecting individuals for mass propagation and deployment.

At $1.52, the price calculated for the methods used (see years two and three reports) was considerably higher than the target of $0.50–$0.60 per rooted cutting (Table 6). This price point is not operationally feasible, although it can be improved (see year three report).

Ramet Production	
Production of ramets from stecklings year one	$ 2,163.00
Production of ramets from stecklings year two	$ 2,915.00
Production of roots from 22 ramets year three	$ 6,600.00
Subtotal	**$ 11,678.00**
Clonal expansion	
Process roots into segments and plant	
Segments processed	12,000
Cost per segment	$ 0.55
Total cost of clonal expansion	$ 6,600.00
Total cost per segment planted	**$ 1.52**

Table 6. Ramet and trembling aspen clonal costs for propagation at Woodmere Nursery.

The number of plants achieved for the outplanting phase of the experiment is also below that required to complete the entire trial and will need to be adjusted in the next phase of the study (Table 7).

		Diameter of Root Material (mm)			
Clone	**Length of Root Material (cm)**	**Near Crown**	**Midpoint**	**Near Growing Tip**	**Number of Segments (2.5 cm in Length, > 1.0 mm Diameter)**
3159	100	1.50	1.00	0.90	322
1154	130	2.50	1.80	1.20	624
3152	155	2.30	1.50	0.90	660
3089	125	2.90	1.70	1.60	1,080
3109	90	1.60	1.00	0.40	480
1152	105	2.00	1.60	0.80	284
3104	135	1.60	1.50	0.90	866
3012	125	2.30	1.70	1.00	960
1007	115	2.00	1.10	0.80	415
3014	120	2.00	1.50	0.90	940
1152	105	1.80	1.40	0.80	600
8041	85	1.20	1.00	0.60	173
1165	100	1.20	1.00	0.60	360
1164	100	1.40	0.75	0.50	120
3137	175	2.10	1.70	1.20	1,113
1158	105	2.00	1.50	1.10	180
3135	90	1.80	1.50	1.00	360
3143	115	1.80	1.20	1.00	300
1159	100	1.60	1.50	1.10	1,260
1160	80	1.90	1.50	1.40	540
1157	80	2.00	1.60	1.20	300
1161	85	1.70	1.40	1.50	660
22	**110**	**1.87**	**1.38**	**0.97**	**12,597**
Total clones	**Average length**		**Average diameter**		**Total ramets**

Table 7. Clone and material production of trembling aspen at Woodmere Nursery.

Bonnyville / Smoky Lake Forest Nursery

Bonnyville Forest Nursery was responsible for the initial propagation phase of this project, handling roots and suckering those roots in 2012 and 2013. Roots were supplied for a total of 30 trees, as per the protocol. In March 2014, after successful rooting of material, 22 of the 30 clones were selected for the bulking-up phase of the project, with the aim of producing 3,000 stecklings per clone.

A total of 16 one-year-old and two-year-old “mother” plants were used for the bulking-up phase carried out at Smoky Lake Forest Nursery using the stacked styro-block method (Figures 22 and 24). This nursery was very successful at producing material, although there was, as always, clonal variability. Table 8 presents the cost estimate per steckling ($1.01) with the proviso that they anticipate being able to reduce that cost further by selecting clones that all root well and achieving economies of scale.

Activity	Cost
Establishment and growth phase	$22,910
Transplanting and hardening phase	$40,450
Over-winter storage costs	$ 3,213
Total costs	$66,573
Total number of stecklings produced	66,000
Cost per steckling	$1.01

Table 8. Cost estimations per steckling using the stacked styro-block propagation method.

Nursery report note: In this trial, the cost per plant produced, including over-winter storage, is right around $1.00 per plant, but it is our firm belief that we will be able to reduce the costs significantly in future production runs. This reduction can be accomplished by selecting the clones with the best possible rooting potential and by mass-producing or at least scaling up the number of plants per clone to reduce the number of clones.

The major component of producing aspen by this method is labour. By simplifying the layout and tracking required with a large number of small clones, the cost will be reduced. If the outplanting trials are successful and larger orders are placed for production, we believe that we can get the cost per plant down into the range of **$0.70–$0.80**. Hopefully this will be seen as a cost-effective way of producing the plants for establishing aspen plantations. (See the year three CCEMC project report for full details on methodology, and comments).

Figure 24. Aspen roots after one growing season using the stacked styro-block system of mass propagation at Smoky Lake Forest Nursery.

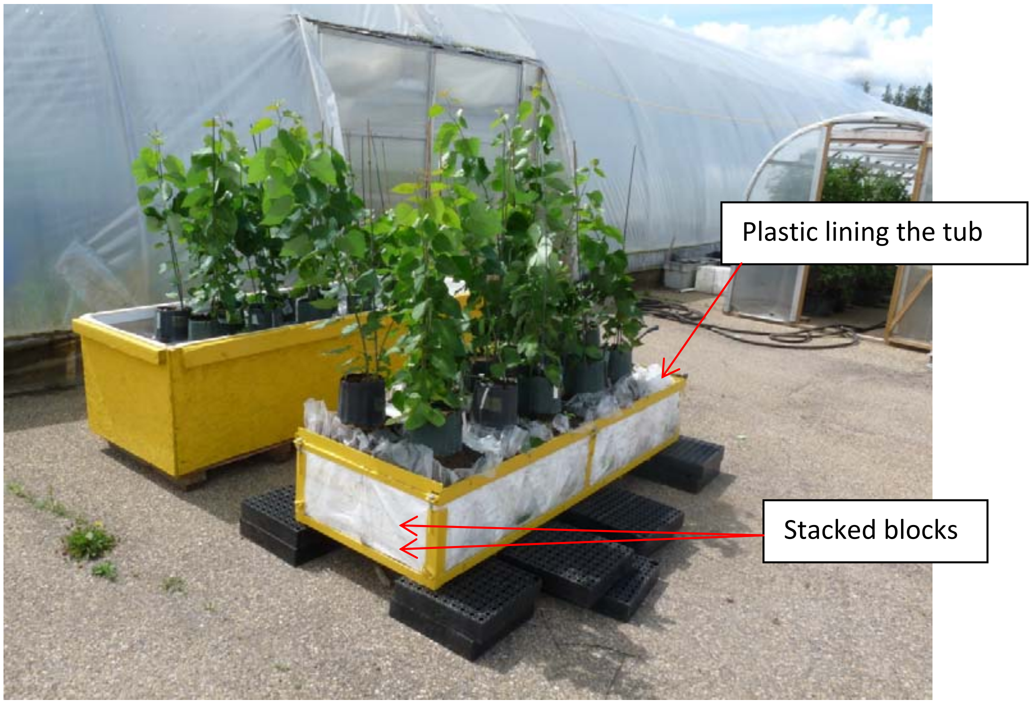

Figure 25. Project II stacked styro-block propagation system showing mother plants grown outside and being watered from the base (plants and styro-blocks inside the tubs).

Project II

Project II was undertaken by Smoky Lake Forest Nursery. It consisted of testing four different methods to refine the stacked styro-block technique—with blocks inside and outside the greenhouse and with top or bottom watering (Figure 25). Eleven clones with 46 mother plants previously obtained from Weyerhaeuser were used in this study.

Based on the results from this project, the greenhouse-grown mother plants watered with drip irrigation from above were ultimately selected for use in Project I.

Summary

Overall, it is clear that meeting the target price to produce clonal aspen material using the methods described elsewhere (annual reports) and in this report is economically challenging when compared to the cost of growing conifer seedlings. Each step in the process, from obtaining healthy rooted suckers from the original roots to growing mother plants with extensive root systems, is relatively labour intensive, requires a reasonably high level of propagation knowledge, and is time sensitive. In addition, the final bulking-up stage requires an additional year in the process.

There are, however, some significant gains to be made once preliminary screening of clones is completed. Due to the variability in the ability of aspen clones to root at each phase in the process, it is clear that an early screening method is needed to eliminate those clones that do not root easily and readily. Furthermore, once the best clones are identified, mother plants can be easily maintained for future mass production. Starting from original roots to produce the initial rooted sucker cuttings is slow, time consuming, and labour intensive.

Given the potential genetic advantages of being able to select and propagate aspen clonally, producing material in the $0.70–$0.80 range may in fact prove economically feasible in the long term.

Appendix 1: Project Linkages to Public Policy

TSARM_PolicyLinkage_2015Jul20.pdf

Appendix 2: Climatic Adaptation of White Spruce and Lodgepole Pine in Alberta

TSARM_ClimateAdapt_SwPl_2015Jul16.pdf

Appendix 3: Projected Changes in Climate for Alberta and Forest Tree Improvement Program Regions

TSARM_ClimateModeling_2015Jul16.pdf