# Climate-Based Seed Transfer:

# Guiding British Columbia's reforestation investments in a changing climate

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***Key messages:***

- *Climate-based seed transfer (CBST) is a critical knowledge investment in BC reforestation programs*
- *Stable and long-term research investments are needed to implement CBST*
- *Risk associated with a conservative and evidence-based CBST system is low and manageable*

The consensus scientific opinion is that climates are warming and will continue to warm. Impacts on forests are apparent now and are expected to increase. Climate-based seed transfer (CBST[3]) has the potential to mitigate billions of dollars of lost timber value over the next century.

## Climate change causes genetic maladaptation

Climate-change-induced stress on forest trees occurs because they are genetically adapted to past climates. As climates increasingly change, trees become maladapted to the climates they are in[4]. Physiological processes such as growth rate and timing, drought resistance, and cold hardiness become less optimized. This manifests as increased susceptibility to pest outbreaks, poorer growth, higher rates of mortality from drought and cold events, and other impacts that reduce health and productivity.

## Opportunity for a positive economic impact

What does genetic maladaptation mean to the economy of BC? The logical expectation is a negative impact, but how negative and what can we do about it?

Genetic adaptation of tree populations to climates takes many centuries because individual trees have long life spans and cannot move . Adaptation occurs only when new seedlings regenerate and are exposed to natural selection by new climatic factors; a slow process. In order to maintain forest productivity and the values that flow from forests, we must not wait to act. We have a wealth of information in the form of genetic research on how different tree populations perform across BC's ecosystems, a world-class made-in-BC climate model (ClimateWNA [5]), and expertise in government, universities, and industry. We also have large operational reforestation programs that plant an average of 250 million trees per year. Together, these factors provide an important opportunity to accelerate the genetic adaptation of forests to climate change and to positively impact timber supply and other services provided by BC's forests.

## Elements of the solution

There are four distinct elements in the process of understanding and managing the genetic adaptation of forests to changing climates. The first is <u>understanding climates</u>, how they are changing and how the ranges of forest trees

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[3] Climate-based seed transfer is the operational transfer of seed used for reforestation in a way that optimizes long-term forest productivity by aligning the genetics of seed used with the future climates of the planting site. Assisted migration is the ongoing process of alignment of genotypes and climates, and it is facilitated by a CBST system. CBST is meant, in this document, to include assisted migration where it is supported by scientific information.
[4] Aitken, S.N., S. Yeaman, J. A. Holliday, T. Wang, and S. Curtis-McLane. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications 1(1): 95-111.
[5] Wang, T. L., Hamann, A., Spittlehouse, D. L., and Murdock, T. Q. 2013. Climate WNA: High-Resolution Spatial Climate Data for Western North America. Bulletin of the American Meteorological Society. Pp 1307-1309.

align with climatic patterns. Extensive work has been done in this area at the University of BC to interpret global climate models in terms of BC forests and to correlate these models with widely used biogeoclimatic information (Wang et al. 2016[6]). The result is the ClimateWNA model that provides a solid platform to predict future climates and forest responses.

The second element needed is a sound understanding of genecology; how natural patterns of genetic diversity align with climates. Again, BC is well positioned with over 50 years of field-based genecology research, expertise in the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), Universities, and industry, and more recent genomics research that is adding to the knowledge base.

Third, provincial policy and policy support tools are necessary to provide a framework for seed transfer for private companies and government agencies undertaking reforestation. This policy framework largely exists now in the form of the provincial Chief Forester Standards for Seed Use[7]. These Standards and underlying support from MFLNRO-operated seed inventory and tracking systems are well established in BC and are currently used for all Crown land and most private land reforestation. Adjustments to these existing systems to accommodate climate-based seed transfer (CBST) are underway.

The fourth element is a large operational reforestation system that can be adjusted to accommodate CBST. Reforestation is well established in BC and includes integrated operations for seed production and procurement, nursery production of seedlings, and planting in logged or disturbed areas. These systems are fully integrated, with private companies undertaking most of the work.

## Incremental CBST costs are small relative to impact

The incremental costs of developing and maintaining a system of CBST are low relative to the overall cost of reforestation systems in BC. These incremental costs fall into three categories:

- Scientific information
- Policy framework
- Adjustments to seed production and inventory

All other reforestation costs are already being incurred and are incented by the existing economic and policy framework. CBST is an incremental investment and adjustment to an existing, well-organized system.

## The costs and benefits of climate-based seed transfer

Modelling forest value flows, climate-change impacts on forests, and factors such as timber price is complex. However, it is feasible to isolate key elements of this system to investigate whether CBST has the potential to add value beyond the cost of implementation. To this end, two models were developed to simulate value at both the provincial and the stand levels.

### Provincial-level economic impact

A provincial-level model was developed to simulate timber production and value while investigating the economic impacts of a broad range of climate-induced forest productivity losses. The purpose of this analysis is to evaluate the sensitivity of long-term value from forests to reduced productivity, while also testing how much value can be retained through the use of CBST.

Cost inputs to the model are limited to the costs of research, policy development and adjustments to seed production. All other elements of BC's forest economic system are already in place and are not expected to change. This allows focus on the sensitivity of economic impact to reductions in productivity and timber availability caused by climate change and the value of interventions to mitigate those changes through CBST.

Figures 1 and 2 illustrate the fundamental issue associated with productivity loss due to climate change. Under an equilibrium climate (Figure 1), presumed to be past climates before anthropogenic climate change, tree seed

[6] Wang T, Hamann A, Spittlehouse D, Carroll C (2016). Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. PLoS ONE 11(6): e0156720. doi:10.1371/journal.pone.0156720

[7] http://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/tree-seed/legislation-standards/chief-forester-s-standards-for-seed-use

sourced within a seed zone and elevation band generally optimize expected production and minimize plantation-failure risk. Sourcing seed from diverging climate areas (illustrated here with only mean annual temperature (MAT) for simplicity) reduces productivity (green line). As climates warm, optimum seed sources for a given planting location are found in areas that had past climates similar to the expected future conditions of the planting location. Figure 2 illustrates this with the green line shifted right to show that seed sources from historically warmer areas are the most productive and local sources are now less productive.

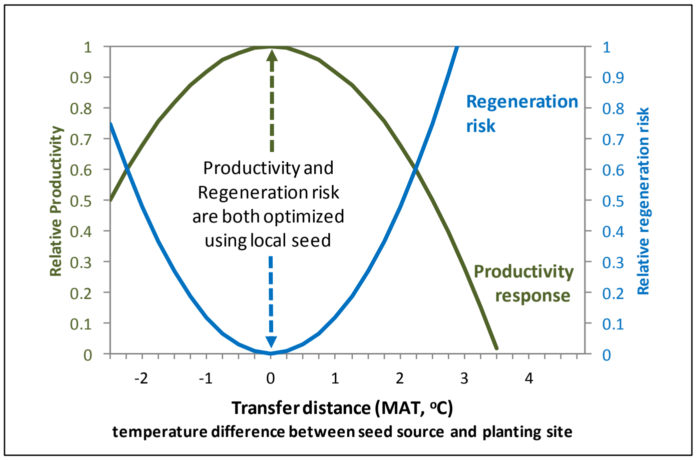


Figure 1. Seed transfer in an equilibrium climate. Genetic adaptation of trees to climates results in a near optimization of productivity and minimization of reforestation risk with the use of local seed.

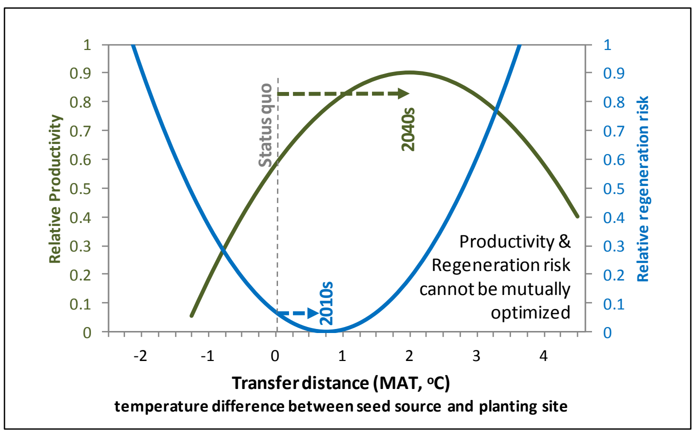


Figure 2. Seed transfer in a changing climate. Optimizing longer-term productivity is becoming out of sync with the minimization of regeneration risk. Finding balance between productivity and risk is an important outcome of climate-based seed transfer.

The actual impacts on any given planted stand in BC will vary greatly. However, it is feasible to ask the question "how much long-term economic impact would occur provincially with varying levels of average productivity loss and with varying levels of our ability to reduce those losses through CBST"? Framing the results as a net present value (NPV) to provincial gross domestic product (direct GDP[8]), using a social discount rate of 3%, illustrates very substantial value from CBST investments both in NPV (Figure 3) and as a benefit-to-cost ratio (Figure 4). The strong driver to these high values is the fact that small investments in CBST leverage very large ongoing investments in reforestation and silviculture.

This analysis relies on the evidence-based assumption that productivity will drop and we can limit this drop partially or, in some cases, entirely through CBST. Within reasonable assumptions of productivity loss and mitigation of the loss, CBST has a very positive benefit-to-cost ratio as illustrated in Figure 4 using the same range of productivity losses under status quo management and recovery through adaptation of seed transfer practices.

[8] See COFI, 2015. BC Forest Industry Economic Impact Study. http://www.cofi.org/industry-info/economic-impact/

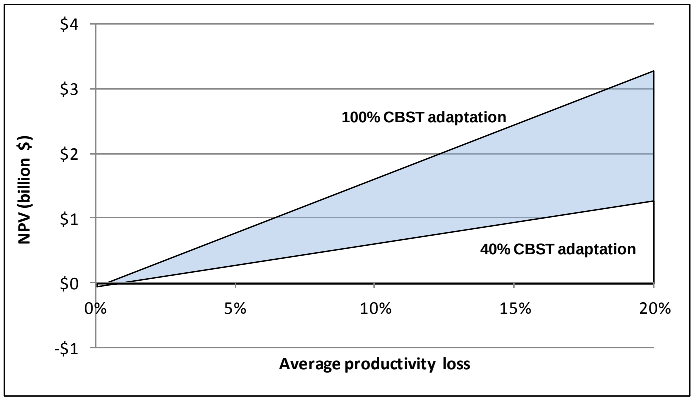


Figure 3. Provincial economic impact in direct GDP as a net present value (NPV) across a range of average productivity losses in provincial forests due to climate change and a range of levels of mitigation of these losses due to improved genetic adaptation under climate-based seed transfer (CBST). A CBST adaptation value of 40% means that, on average, productivity losses to climate change could be reduced by 40%. A value of 100% means averting all productivity losses through CBST. These scenarios were run over a 100 year period from present using a 3% social discount rate and an assumed annual CBST research cost of $2.5 million per year.[9]

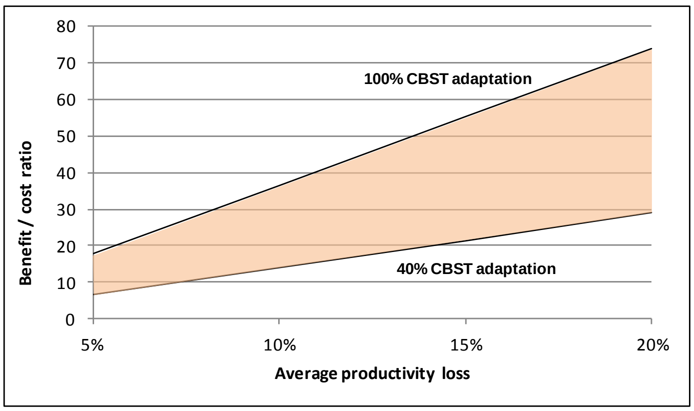


Figure 4. Benefit-to-cost ratios for a range of average productivity losses in provincial forests due to climate change and a range of levels of mitigation of these losses due to improved genetic adaptation under CBST. These scenarios were run over a 100 year period from present using a 3% social discount rate and an assumed annual CBST research cost of $2.5 million per year.

## Stand-level value

A stand-level model was constructed to investigate the potential impact of CBST using output from the TASS growth and yield model developed by the MFLNRO[10]. This stand-level model allows evaluation of NPV from the perspective of a Licensee concerned primarily with net cash flow after the removal of conversion cost and stumpage fees. Heightened risk of early plantation failure could result from the use of seed that is better adapted to an expected future climate than it is to the current climate. Although anticipated seed migration distances will be conservative, with small increments over time, there may be a trade-off between increasing early regeneration risk and reducing the probability of mid-rotation stand failure through the use of better-adapted seed sources. These risk factors are introduced as probabilities-of-occurrence to understand the impact on an average stand given that many stands will be planted.

Figure 5 depicts expected licensee profit using an assumption that they are 10% of conversion costs for a realistic range of productivity and risk scenarios for a lodgepole pine stand with a site index of 19. An expected full-rotation productivity loss of 10% from maladaptation and a discount rate of 6% are used. These results demonstrate that value drops with increasing risk of early plantation failure due to genetic maladaptation when seed most suited to a future climate is used. However, this loss is offset by a 60% reduction in the probability of mid-rotation losses caused by genetic maladaptation. The financial trade-off shown here illustrates that finding an optimum balance

[9] Log values used for this analysis are based forest sector GDP (forestry, logging, support activities, wood-product manufacturing, and paper manufacturing) from Statistics Canada's CANSIM 379-0030, 2012.
[10] https://www.for.gov.bc.ca/hts/growth/tass/tass_overview.html#

between productivity gains and risk at both the time of stand regeneration and later stand development are important. As there is more certainty about climates in the next two decades than beyond this period, CBST systems will be designed to avoid increasing the near-term risk of plantation failure.

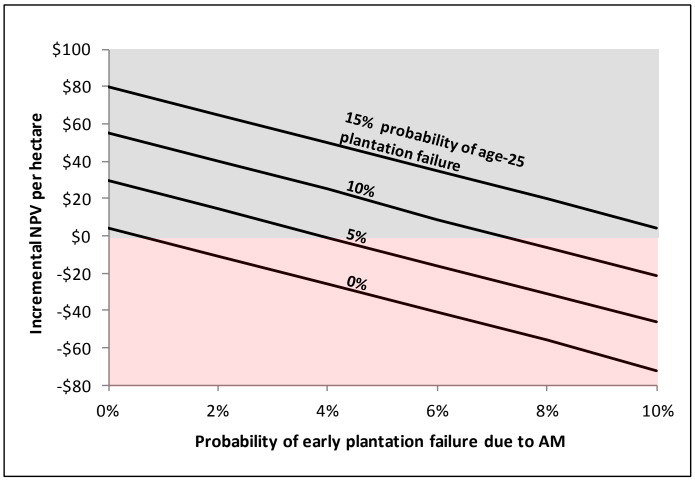


Figure 5. Incremental net present value (NPV) for a typical lodgepole pine stand (site index 19) using discounted (6%) profit at harvest under the assumption that profit is 10% of log conversion cost. Values graphed are the NPV difference between status quo seed use and CBST-sourced seed. Shown are the effects of a range of probabilities of early plantation failure due to CBST and a range of probabilities of age-25 failures that were averted due to the use of better-adapted seed.

## CBST policy implementation

The MFLNRO has developed a scientific framework and is currently developing new policy and implementation support for CBST. A successful CBST system in BC will require ongoing scientific research to evaluate and model climate-change impacts, genecological research to evaluate a range of seed sources exposed to different climatic, insect and disease stresses under field conditions, and genomics research to complement field-based data and to better link tree genomes with specific climatic factors, risks of injury from extreme events, and adaptive diversity. The anticipated framework will ideally support the incorporation of new information into seed transfer policy in a way that allows periodic adjustment to seed transfer without requiring substantive change to seed planning and procurement systems.

A further need under a CBST system will be adjustments to existing seed orchards to provide adequate amounts of seed for deployment ranges that become larger or smaller. The need for such adjustments is anticipated by stakeholders represented through the Forest Genetics Council of BC.

## Conclusion

CBST investments have a very high potential payoff due to their impact on BC's extensive system of forest regeneration and subsequent timber production. These relatively low-cost investments are linked to long-term research and policy needs that require resourcing stability. The expected risks are low and manageable within a policy framework that is continually informed by scientific knowledge and supported by stakeholder collaboration and implementation through existing systems.