Seed Zones in Alberta: Applications to shrubs used in reclamation

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Outline

- Overview of policies applicable to plants used in reforestation and reclamation on Alberta crown (public) land
- Concept of plant genetic adaptation to the environment
- History of delineation and application of seed zones in Alberta
- Recent developments in application of seed zones for forestry in Alberta
- Application of existing Alberta seed zones to reclamation shrubs
- The role of ATISC in shrub provenance research and seed biology and technology.
Provincial Policy for the use of Native Plants for Revegetation/Reclamation - Objectives

Following are international and national guiding policies that outline the responsibilities for the conservation and sustainable management of forest genetic resources in Alberta:

- **United Nations Convention on Biological Diversity (UNCBD) 1992 ratified by Canada with the following objectives:**
  1. conservation of biodiversity
  2. sustainable use of biological resources
  3. fair and equitable sharing of benefits resulting from the use of genetic resources

- **The Canadian Biodiversity Strategy (1995) developed through broad based consultation and support by provinces, territories and stakeholders with the following objectives:**
  1. conserve biodiversity and use biological resources in a sustainable manner
  2. improve our understanding of ecosystems and increase our resource management capability
  3. promote understanding of the need to conserve biodiversity and use biological resources in a sustainable manner
  4. maintain or develop incentives and legislation that support the conservation of biodiversity and the sustainable use of biological resources
  5. Work with other countries to conserve biodiversity, use biological resources in a sustainable manner and share equitably the benefits that arise from the utilization of genetic resources
Provincial policies/guidelines that outline the responsibilities for the conservation and sustainable management of forest genetic resources in Alberta:

- Native Plant Revegetation Guidelines for Alberta (2001)

The Alberta government is responsible to ensure the protection of the provinces natural resources on a sustainable basis for the benefit of Albertan’s and there is enhanced understanding of the value of maintaining ecosystem function and biological diversity within the native landscapes particularly on public land.

Stated objectives include:

- Encourage the eventual establishment of native plant communities within native landscapes;
- Promote the use of native species in the revegetation of disturbed sites within native plant communities within the Green and White Areas of Alberta;
- Promote consistency of native plant material use among regulatory jurisdictions;
- The collection site of native plant material should be as close as possible to the disturbed site (within the same Natural Region);
- Acknowledge the site specific role of non-native species to meet short-term revegetation objectives or meet acceptable land use needs;

- Alberta biodiversity strategy (under draft and reportedly imminent)
• **Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands (2010)**
  1. Desired plants for forested lands are those species which are representative of the natural subregion, ecosite and plant community

• **Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region (2010)**
  1. Reclaimed plant communities should have species characteristic of native plant communities in the oil sands region;
  2. Trends of vegetation community and structure development on reclaimed landscapes should be similar to native plant communities in the oil sands region;
  3. Reclaimed ecosystems should have developmental trajectories that satisfy land use objectives, and have characteristics that provide resilience against natural disturbance events.

• **Alberta Forest Genetic Resource Management and Conservation Standards (FGRMS) 2009, (first implemented in 2003 as The Standards for Tree Improvement in Alberta (STIA))**
The only known provincial standards dealing with plant genetic resource management on Public lands in terms of genetic diversity, genetic adaptation, genetic conservation, genetic productivity and plant health
The Native Plant Revegetation Guidelines for Alberta (2001) provides some definitions:

- **Native plant community**: a plant community that is dominated by native plants,
- **Native species**: plant species that are indigenous to a particular natural region; they were in that region prior to the time of Euro-American settlement,
- **Native plant material**: seeds, rootstocks and other propagative materials' from plants that are indigenous to a particular region,
- **Native plant species**: those that are indigenous to a particular region. They have adapted over time in association with landscape and climate.

These definitions and the previous guidelines and standards imply, at some level, evolution in place at origin and regional genetic adaptation. The question then becomes, what constitutes a region that is congruent with patterns of detectible and important genetic adaptation for the plants we are working with?
Plant species are composed of genetically differentiated populations and these genetic differences are manifested:

- Morphologically
- Physiologically
- Molecularly
- Biochemically
- Through physical measurement (e.g., growth)
- Through susceptibility to pests and diseases
- In response to environmental stresses (e.g., drought, frosts)
- Through timing of initiation and cessation of growth and flowering
- etc.

Genetic variation arises from **mutation** which creates **allelic variants** within a population that are **recombined through reproduction** (recombination) into **genotypes**.

With modification by the environment, the same genotype produces different **phenotypes** (an expressed form of an individual or population) that can be

- Physically observed (morphology), quantitatively measured (e.g., growth), chemically detected, etc.
- There are many different ways to detect existence of genetic and phenotypic variability in the population and species.
This cyclic process of **mutation-recombination-natural selection** and associated forces of **migration** or **gene flow** (exchange of genes among populations) and **random genetic drift** (random loss of variability in small isolated populations) is what is called **EVOLUTION**.

The concept of evolution by **Natural Selection** encompasses both
- The biological processes that occur in the cell of the organism and,
- The pressure the environment exerts on the genotype to produce the phenotype of an individual

**Natural selection** sifts the population so that only individuals capable of surviving, growing and reproducing adequately in the prevailing environment remain.

Because the environments over which a species is naturally found vary, the **genetic differentiation** of plant populations usually follows the **pattern of variation in the environment** (normally climate, day length, etc.).
Concept of plant genetic adaptation to the environment

- The pattern of genetic variation in wild plant populations can be detected
  - In field experimentation using the same material (clones or seed) planted over a wide range of climatically distinct environments, or
  - In the laboratory for selected biochemically detectable molecular and/physiological signatures or markers.

- When field experimentation or laboratory studies are yet to be done but decisions on transferability of seed and clones have to be made (in forestry, reclamation, etc.), **climatic similarity and geographic distance between the seed source and planting site provides a good safeguard against genetic maladaptation** (poor or lack of adaptation).

- Therefore, the role of biologists, foresters, agrologists and all people who manage vegetation in domesticated plant communities or artificially regenerated plant communities in the wild is **to ensure that plants are properly matched with an environment similar to the one in which the populations evolved** i.e. there is a causal link between genetic variation and environmental variation particularly climate.
History of delineation and application of seed zones in Alberta

- **Seed zoning** is a vegetation management tool whereby a country, province or state is divided into regions that are “fairly” climatically and/or ecologically homogeneous to facilitate collection and use of seed with minimum risk of compromising plant adaptation to the environment.

- **Seed zoning also functions to conserve genetic diversity within a species** because it preserves a mosaic of populations that inhabit a wide range of environments, which make up the species’ natural range.

- Because of a long history of artificial regeneration and tree planting as well as the longevity of trees, **seed zoning, as a genetic maladaptation risk management practice** is better understood in forestry than in reclamation work with shrubs and herbaceous material.

- A similar practice exists in agriculture (**Agro-ecological zoning**) which is based on climate, soils and landform to optimize productivity by adopting crop cultivars or varieties that are better suited to the environment.
History of delineation and application of seed zones in Alberta

SEED ZONES are geographic subdivisions of the species natural range based on climatic, ecological and genetic criteria, within which seed is collected and planted.
There are **90 seed zones in Alberta**, which reflects the immense environmental variability of the province. Generally,
- Seed zones in the boreal forest are larger and with minor exceptions tend to follow a south-north climatic trend.
- Seed zones in mountainous regions (foothills, Rocky mountains & boreal highlands are smaller and follow a climatic trend from lower to higher elevation).

Alberta seed zones are subdivisions of Natural Subregions; the administrative rule is,
- Collect seed or vegetative planting materials within a specified seed zone and plant within the boundaries of that seed zone,
- Planting seedlings and clonal materials outside the seed zone of origin requires a **variance approval** from Alberta Environment and Sustainable Resource development (ESRD).

Currently, the same seed zones are applicable to all coniferous and deciduous species,
- While plant species differ in their reproductive biology and life histories, the same agents of natural selection (e.g., climate and photoperiod or day length) determine their population genetic structure, which is the basis of ESRD seed transfer guidelines.
- Research shows that the patterns of population genetic structure of coniferous and deciduous species are similar and are directly explained by characteristics of the environment in which the species is naturally found.
The current Alberta seed zones were developed based on,
  - Climatic information.
  - Natural Subregions and Ecodistricts
  - Early results of Alberta-wide conifer provenance trials.

Developed in this way, Alberta seed zones are consistent with the BIOME concept whereby plant subdivisions are defined by ecological and physiognomic characteristics of the vegetation BUT,
  - These subdivisions correspond well with climatic regions of the area even though non-climatic factors may also be important.
  - Emphasize the adaptation of the organism (e.g., plants) to the environment through inclusion of information on the adaptive genetic variation found in conifers through provenance testing.


Since the Alberta seed zones were delineated in 2005, additional measurements of provenance trials have been analyzed and results integrated into seed transfer guidelines.
Example of results from white spruce provenance trials

Fort McMurray (P1 = -1.50)  
\( R^2 = 0.73 \)

Lac La Biche (P1 = -1.27)  
\( R^2 = 0.67 \)

Edson (P1 = 2.03)  
\( R^2 = 0.70 \)

Rocky Mountain House (P = 2.89)  
\( R^2 = 0.44 \)
Example of results from white spruce provenance trials

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<th>$R^2$</th>
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<tbody>
<tr>
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<tr>
<td>Slave Lake (C)</td>
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<td>Grande Prairie (D)</td>
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<td>Edson (E)</td>
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<td>Calling Lake (H)</td>
<td>0.63</td>
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<tr>
<td>Hangingstone (J)</td>
<td>0.70</td>
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Example of results from white spruce provenance trials

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<tbody>
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<tr>
<td>Hangingstone (J)</td>
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Example of results from white spruce provenance trials

- Alberta conifer (white spruce, black spruce, tamarack, lodgepole and jack pine) provenance trials show similar results,
  - On a given site, populations with the best growth are either local ones or those climatically similar to the site.
  - Even where the local population is not the best, the alternative better population is not too far from the planting site (e.g. within 2° of latitude or 200 altitudinal metres). NOTE: As with all data, exceptions to the rule may be found.
  - Populations from higher latitudes and higher elevations grow poorly, except when planted in their native environments.

- As previously illustrated, climatic and geographic (latitude & elevation) descriptors yield similar patterns of population genetic variation in forest trees.
  - Climate varies with latitude (south-north displacement) and elevation (accounts for variation in temperature, precipitation and length of growing season),
  - In addition to variation in temperature and length of growing season, latitude accounts for variation in day length, which elevation cannot.

- THEREFORE, for practical reasons, it is easier to base seed transfer guidelines on geographic (latitude) and topographic (elevation) descriptors than climate as this information is easily available and understood by practitioners on the ground.
Based on conifer provenance trials, seed transfer guidelines in Alberta were revised in 2009 to allow,

- Northward transfer of seed across seed zone boundaries by a maximum of 2° of latitude.
- Transfer of seed across seed zone boundaries from a lower to a higher elevation by a maximum of 200 altitudinal metres.
- **NOTE 1**: Transfer of seed from north to south and from a higher to a lower elevation is not permissible—it will not affect survival but will reduce growth and productivity.
- **NOTE 2**: Because of the topographic nature Alberta, northward transfer of seed at mid and higher latitude may appear as transfer from a higher to a lower elevation—ESRD can help with this confusion.
- **NOTE 3**: Seed zones have not been changed—all new rules are implemented through the variance application system which are easy to obtain.

These changes have been introduced because,

- Provenance trials show that populations found in adjacent regions of currently separated seed zones may have similar growth potential (**Note**: growth potential was a major trait used to assess population differences).
- Due to projected changes in climate (esp. temperature), the risk from frosts and winter-related damages for populations from relatively warmer environments is reduced.

There are other factors—hybridization, potential for insects and diseases, etc. that ESRD considers in approving variance applications.
Application of existing Alberta seed zones to reclamation shrubs

- Views that the existing Alberta seed zones are based on studies and information on forest trees (esp. conifers), and are likely too small and not appropriate for shrubs assumes that:
  - Trees and shrubs are different in terms of adaptive genetic variation;
  - The traits (characters) of importance in forestry (esp. growth & productivity) are different from those in reclamation where survival and establishment are important;
  - Shrub seed zones could be developed that take into consideration the characteristics of shrubs and variation in traits that are important in reclamation and these seed zones can likely be larger than forest tree seed zones.

- Trees and shrubs are different BUT the reproductive biology and evolutionally processes that determine genetic diversity in natural plant populations are the same for trees and shrubs. These views are not likely correct

- For both trees and shrubs, the extent by which adjacent populations differ genetically depends on
  - The extent of environmental variability – how strong is natural selection (the higher environmental variability-the stronger the selection pressure –the higher the genetic differentiation).
  - The rate of gene exchange (through pollen and seed dispersal) among adjacent populations – the greater the gene exchange the lower the genetic differentiation and vice versa.
  - Some historical factors that may limit the size of the founding population or limit gene exchange among populations.
Application of existing Alberta seed zones to reclamation shrubs

- Although ESRD does not have a provenance testing programs for shrubs, certain characteristics of shrubs can adequately explain their probable biogeography,
  - Small multi-stem understory vegetation;
  - Small size and position under the tree canopy which restricts pollen dispersal;
  - Pollen and seed (flowering plants) dispersed by birds and animals over short distances;
  - Expect genetic differentiation over shorter distances than in coniferous trees which are wind pollinated and seed is wind dispersed.

- An excellent review paper by Linhart and Grant (1996) in Ann. Rev. Ecol. Syst. 27: 237-277) **strongly suggests that shrubs and herbaceous plants are genetically differentiated at much shorter distances than forest trees.**

- There are numerous molecular and isozyme genetic variation studies in shrubs showing considerable genetic diversity.
  - Could be adaptive or non-adaptive.
  - Need to study amount and pattern of variation for adaptive traits.
A recent literature review (see Shauna-Lee Chai et al. 2013) of the life histories of shrubs commonly used for reclamation in Alberta shows that, pollination, mating and seed dispersal mechanisms for species such as Alder (Alnus spp.) are similar to that of Alberta spruces:

- The pattern of genetic differentiation for these species should be similar to that of other native trees found in Alberta and such species could use the current seed zone system.

This review organizes common reclamation species into guilds based on mating systems and genetic architecture and for some recognizes that where pollination and seed dispersal is by insects, birds and other animals, the resulting mating system differences will effect the amount and kind of genetic variation. For these shrubs it is likely that:

- There will be population differentiation over shorter distances compared to forest trees (esp. conifers)
- seed zones based on genetic field testing for some may be smaller than the existing Alberta seed zones.

Like forest trees and other plants, shrubs used for reclamation in Alberta need to be genetically adapted to places where they are planted:

- This allows them to **survive, grow** and **reproduce** adequately while genetically evolving to meet the challenges of the changing environment.
- Traits of interest for forest trees (e.g., **survival, growth** and **productivity**) are the same for reclamation shrubs, however, they may be measured differently – reclamation shrubs should measure growth and productivity in terms of **vegetative biomass** which enables a shrub provenance to capture the reclaimed site quickly.

If followed as intended, existing Alberta seed zones should provide a good framework in which to operate while collecting and using shrubs for reclamation:

- Based on the reproductive biology of shrubs commonly used for reclamation in Alberta, shrub seed zones based on common garden studies for some species are not likely to be as large as the current seed zones while some may be similar;
- In the interim, as with tree seed transfer rules prior to provenance testing, current seed zones and transfer rules should adequately manage risk of maladaptation and meet gene conservation needs for shrubs.

Provenance trials for shrubs should be instituted as they will provide additional knowledge of the genetic architecture of plants increasingly used in artificial regeneration on public land where only anecdotal knowledge currently exists:

- Not having these trials currently is not an impediment to regulating shrub seed transfer within the current seed zone system;
- These trials will be very useful in managing adaptation under conditions of anticipated climate change.
Due to its expertise and experience with forest tree species provenance trials, the Alberta Tree Improvement and Seed Centre (ATISC) can advise on shrub provenance trials to capture a broad range of populations and test environments and maximize knowledge gained from existing long term experiments.

ATISC has begun to provide seed storage services for shrubs at the ESRD/ATISC seed bunker in Smoky Lake in recognition of the need to support adapted deployment and genetic risk management under the new and expanding practice of artificial regeneration for reclamation work.

ATISC has expertise in seed biology and technology and is interested in cooperating to develop protocols on handling, long-term storage and germination of seed for shrubs commonly used for reclamation work in Alberta.

Ultimately, adaptation and genetic risk management in reclamation and reforestation is an issue of professional ethics and sustainable forest management practice necessary for continued social license to operate and ESRD/ATISC has a role in assisting industry while assuring good stewardship in forest genetic resource management.
Thank You!