Assisted Migration as a Tool for Climate Change Adaptation in Canada

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Outline

- Definition and background
- The debate
- AM in the forestry context
- State of AM in Canada
- Recent and ongoing research at GLFC
Projected Climate Change in Canada

(Mean Annual Temperature)

CanESM2, RCP 4.5
(2071-2100 minus 1971-2000)

CanESM2, RCP 8.5
(2071-2100 minus 1971-2000)
Assisted Migration
- A brief history -

- involves movement of organisms to locations outside traditional range limits in response to climate change.

- First attributed to Peters and Darling, 1985:

  “If reserves do not retain necessary thermal or moisture characteristics, individuals of disappearing species may have to be transferred to new reserves. For example, warmth adapted ecotypes or subspecies may have to be transplanted to reserves nearer the poles.”

  “Such transplantations, particularly involving complexes of species, will often be difficult, but applicable technologies are being developed…”

Assisted Migration
- A brief history, cont’d -

- since 2006 there has been an explosion of articles on the topic
- focus has been on the scientific, ethical, and regulatory challenges
- a limited number of AM projects have been undertaken

The number of scientific articles mentioning assisted migration.
Source: Hälfors et al. 2014, updated by J. Pedlar June 2017
Assisted Migration
- Evolving Terminology -

- over 40 names applied to the phenomenon
- assisted migration is the most popular term
- assisted colonization and managed relocation gaining ground

Assisted Migration
- The Debate: Those Opposed -

“Assisted colonization is tantamount to playing ecological roulette”
- Ricciardi and Simberloff, 2009 -

- species may become invasive/harmful at new location
- may transmit disease to new location
- may hybridize at new location
- AM is not economically feasible
- over-collection of target species within current range

Impacts of red squirrel introduction in Newfoundland.
Assisted Migration
- The Debate: Those in Favour -

“Climate change changes everything.”
- Seddon, 2010 -

- AM offers a chance to save species that would otherwise be lost
- managing species within historical ranges is no longer possible
- risks can be managed through careful environmental assessments and short movement distances

Source: Torreya Guardians website.
http://www.torreyaguardians.org/
Assisted Migration
- The Debate Continues -

- These are tough issues with no simple solutions – this stuff makes your head hurt!

- Opinions are ultimately based on ethical perspectives; particularly one’s view of the relationship between nature and humans

- A way forward: there are different types of AM, that make the debate more nuanced than often portrayed
AM in the Forestry Context

- AM in the forestry context is very different than the original conception of AM in the context of biodiversity conservation.

Forestry-related AM is generally aimed at widespread and abundant tree species. Proposed movements would occur either within (assisted gene flow) or slightly beyond (assisted range extension) current range limits.
AM in the Forestry Context
– Movement Logistics, Cont’d –

- Most commercial tree species span a wide climatic range
- The 18 species shown here occupy temp. and precip. ranges of 18 C and 1960 mm on average
- Climate migration distances being advocated in forestry AM are in the range of 1.5 to 3 C

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Temperatures Occupied (C)</th>
<th>Precipitation Occupied (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar Maple</td>
<td>Acer saccharum</td>
<td>0.4 – 19.5</td>
<td>362 – 2127</td>
</tr>
<tr>
<td>American Beech</td>
<td>Fagus grandifolia</td>
<td>0.7 – 21.0</td>
<td>633 – 2082</td>
</tr>
<tr>
<td>Tamarack</td>
<td>Larix laricina</td>
<td>-7.3 – 10.3</td>
<td>292 – 1713</td>
</tr>
<tr>
<td>Sweetgum</td>
<td>Liquidambar styraciflua</td>
<td>6.7 – 22.7</td>
<td>876 – 1866</td>
</tr>
<tr>
<td>White Spruce</td>
<td>Picea glauca</td>
<td>-11.9 – 10.6</td>
<td>255 – 3358</td>
</tr>
<tr>
<td>Black Spruce</td>
<td>Picea mariana</td>
<td>-9.0 – 9.9</td>
<td>278 – 3570</td>
</tr>
<tr>
<td>Jack Pine</td>
<td>Pinus banksiana</td>
<td>-4.8 – 13.0</td>
<td>328 – 1623</td>
</tr>
<tr>
<td>Lodgepole Pine</td>
<td>Pinus contorta</td>
<td>-7.5 – 12.5</td>
<td>221 – 4185</td>
</tr>
<tr>
<td>Slash Pine</td>
<td>Pinus elliottii</td>
<td>13.3 – 23.7</td>
<td>1068 – 1745</td>
</tr>
<tr>
<td>Ponderosa Pine</td>
<td>Pinus ponderosa</td>
<td>-1.3 – 16.3</td>
<td>195 – 2292</td>
</tr>
<tr>
<td>Red Pine</td>
<td>Pinus resinosa</td>
<td>-0.4 – 13.5</td>
<td>423 – 1672</td>
</tr>
<tr>
<td>White Pine</td>
<td>Pinus strobus</td>
<td>-1.1 – 17.2</td>
<td>496 – 2141</td>
</tr>
<tr>
<td>Loblolly Pine</td>
<td>Pinus taeda</td>
<td>8.8 – 22.6</td>
<td>940 – 1904</td>
</tr>
<tr>
<td>Trembling Aspen</td>
<td>Populus tremuloides</td>
<td>-6.5 – 12.9</td>
<td>221 – 3503</td>
</tr>
<tr>
<td>Black Cherry</td>
<td>Prunus serotina</td>
<td>1.7 – 22.6</td>
<td>461 – 2187</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>Pseudotsuga menziesii</td>
<td>-3.5 – 16.0</td>
<td>195 – 3323</td>
</tr>
<tr>
<td>White Oak</td>
<td>Quercus alba</td>
<td>1.4 – 20.5</td>
<td>440 – 2104</td>
</tr>
<tr>
<td>Northern Red Oak</td>
<td>Quercus rubra</td>
<td>1.3 – 19.7</td>
<td>546 - 2130</td>
</tr>
</tbody>
</table>
AM in the Forestry Context

– Risks –

- The focus on assisted gene flow, reduces many of the risks typically associated with AM

- These risks still exist with assisted range expansion, but negative impacts may be less likely with intracontinental plant movements

This is not to say that forestry AM is without potential risks:

- Errors could be made when selecting populations for assisted migration
- Risk of disease transmission
- Could promote climatically resilient populations at the expense of existing genetic diversity

Many of these risks are already part of modern forest management
AM in the Forestry Context

– Feasibility –

- Forestry AM benefits from a variety of existing resources:
  - Provenance data
  - Seed procurement and storage systems
  - Plantation establishment best practices

- Similar resources do not exist in most species conservation scenarios
AM in the Forestry Context

– Scope –

- ~ 1.5 million hectares reforested annually in Canada and US
- ~ 5 million hectares harvested or burned annually and allowed to regenerate naturally
- Would AM be extended into these areas?
- Species conservation projects likely at a much smaller scale
AM in the Forestry Context

– Costs and Benefits –

- Forestry AM should add relatively little to existing operating costs
- Increased monitoring may be required
- Studies have suggested that AM could help to mitigate growth losses of up to 10-40% under climate change
- Not just about $$$; may also help maintain ecosystem functions provided by key forest species

AM in the Forestry Context
– Facilitating Other Types of AM –

- Current focus is on assisted gene flow, but that could change in the (near?) future
- Other forms of AM (assisted range extension, species conservation, designer ecosystems, etc.) could be incorporated into forestry regeneration activities
- Could change narrative around forestry impacts
The State of Forestry AM in Canada
– Policy and Practice –

- **British Columbia** altered policies to allow greater upward seed transfers (2008) and range expansion of western larch (2010); new climate-based seed transfer system coming in March 2018

- **Alberta** allows seed zone exceptions with variance request; exploring use of Fd and Pp as regen spp; reviewing seed transfer system

- **Ontario** allows seed zone exceptions with variance request; encouraging multi-seedlot plantations; reviewing seed transfer system

- **Quebec** allows seed zone exceptions with variance request; mixing northern and southern seed sources; new zones for orchard seed planned for 2018

**Planting the forest of the future**

While conservation biologists debate whether to move organisms threatened by the warming climate, one forester in British Columbia is already doing it. Emma Marris reports.
The State of Forestry AM in Canada
– Tools: SeedWhere –

- A simple, climate matching tool
- Uses the Gower Index to indicate climate similarity between any two locations
- Can be used with any number of climate variables
- Shows climatic similarity under both current and future climates
- Similar to Seedlot Selection Tool in U.S.

**Seed Sources for Sudbury, ON**

**Deployment Areas for Sudbury, ON**
Much of our work involves data from provenance trials.

These trials involve planting various seed sources (or provenances) at a number of test sites (or common gardens).

Various metrics (e.g., height, DBH, survival) are measured through time.

Originally established to identify superior seed sources for forestry gains, but now valuable for climate change research.
both species showed a significant relationship with MAT (R² ~ 0.35; MAE ~ 12%):

\[ H_{33} = 7.29 + 0.568\text{MAT}_s - 0.074\text{MAT}_s^2 + 0.044\text{MAT}_p - 0.015\text{MAT}_p^2 + 0.031\text{MAT}_s\text{MAT}_p \]

\[ H_{16} = -4.468 + 1.942\text{MAT}_s - 0.093\text{MAT}_s^2 + 0.270\text{MAT}_p - 0.022\text{MAT}_p^2 + 0.001\text{MAT}_s^2\text{MAT}_p^2 \]

showed strong response across test sites, with optimal MAT of ~4.5°C for black spruce and ~10°C for white pine (= strong ‘environmental effect’)

weak response across provenances at a given test site (=weak ‘genetic effect’), which implies relatively little impact of seed movements
URFs can also incorporate climate change by substituting future climate values into the equation.

For white pine in Ontario, growth is projected to increase with climate warming.

Assisted population migration appears to have little impact on future growth rates.
URFs can also incorporate climate change by substituting future climate values into the equation.

For black spruce in Ontario, growth is projected to increase in the northern part of the range, but decline in the south.

Assisted population migration has potential to significantly improve future growth rates.
AM-related Research  
- Range Position Theory -

- Using provenance data, we showed that tree populations often exhibit an optimum temperature for growth.

- This optimum was located in the southern portion of the range.


- Recently published these findings:
AM-related Research
- Range Position Theory, Cont’d -

- Implications for forest response under CC:
  - Northern populations expected to benefit from some CC
  - Southern populations expected to decline
AM-related Research
- Range Position Theory, Cont’d -

- Existing climate change resilience could be leveraged by forest regeneration/restoration programs
- Species with bulk of range lying south of planting site may be highly suitable for planting
- Species distributed mostly north of the planting site may be unsuitable
- Approach identifies populations that are both native and resilient to CC
A ‘range position metric’ (RPM) can be calculated as the climatic distance between the prospective planting site and the range centre of each species in the local species pool:

$$\text{RPM} = (\text{MAT}_{\text{range centre}} - \text{MAT}_{\text{planting site}})$$

Rank species according to RPM value

Climatic information available at: www.planthardiness.gc.ca

<table>
<thead>
<tr>
<th>Common Name</th>
<th>MAT at Range Centre</th>
<th>MAT at Planting Site</th>
<th>Range Position Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ten most climatically suitable native species at North Bay, ON:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green ash</td>
<td>10.9</td>
<td>4.3</td>
<td>6.6</td>
</tr>
<tr>
<td>Red Maple</td>
<td>10.8</td>
<td>4.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Ironwood</td>
<td>10.4</td>
<td>4.3</td>
<td>6.1</td>
</tr>
<tr>
<td>American elm</td>
<td>10.1</td>
<td>4.3</td>
<td>5.8</td>
</tr>
<tr>
<td>Red Oak</td>
<td>9.8</td>
<td>4.3</td>
<td>5.5</td>
</tr>
<tr>
<td>American beech</td>
<td>9.8</td>
<td>4.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Manitoba maple</td>
<td>9.3</td>
<td>4.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Sugar maple</td>
<td>7.5</td>
<td>4.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Black cherry</td>
<td>7.5</td>
<td>4.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Basswood</td>
<td>7.5</td>
<td>4.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Ten least climatically suitable native species at North Bay, ON:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black spruce</td>
<td>1.0</td>
<td>4.3</td>
<td>-3.3</td>
</tr>
<tr>
<td>Jack pine</td>
<td>1.1</td>
<td>4.3</td>
<td>-3.2</td>
</tr>
<tr>
<td>White spruce</td>
<td>1.2</td>
<td>4.3</td>
<td>-3.1</td>
</tr>
<tr>
<td>Showy mountain-ash</td>
<td>2.2</td>
<td>4.3</td>
<td>-2.1</td>
</tr>
<tr>
<td>Eastern larch</td>
<td>2.3</td>
<td>4.3</td>
<td>-2.0</td>
</tr>
<tr>
<td>Trembling aspen</td>
<td>2.5</td>
<td>4.3</td>
<td>-1.9</td>
</tr>
<tr>
<td>Balsam poplar</td>
<td>2.6</td>
<td>4.3</td>
<td>-1.7</td>
</tr>
<tr>
<td>Balsam fir</td>
<td>2.9</td>
<td>4.3</td>
<td>-1.4</td>
</tr>
<tr>
<td>Eastern white cedar</td>
<td>3.7</td>
<td>4.3</td>
<td>-0.6</td>
</tr>
<tr>
<td>White birch</td>
<td>3.9</td>
<td>4.3</td>
<td>-0.4</td>
</tr>
</tbody>
</table>
AM-related Research
- Range Position Theory, Cont’d -

- How widespread is the range position effect?

- What about climatic factors other than temperature, e.g., drought?

- Clearly does not address all forest restoration objectives; e.g., rare species conservation, productivity

- Best considered one tool in the forest restoration toolkit
AM-related Research
- Survival Functions -

- Survival is an important consideration when moving seeds
- How far can seeds be moved and still survive in the short term?
- We have started to explore this question using provenance data
- For lodgepole pine, seeds can be moved ~4C northward and still maintain high levels of survival at age 32
- Relationship is very noisy!

Lodgepole Pine
Survival = 75.74 + 0.51*MAT - 0.60 MAT^2; R^2 = 0.15

Data Credit: Greg O’Neill, BC Ministry of Forests
Black spruce shows a weak relationship between survival and seed transfer distance.

Seeds can be moved ~6°C northward and still maintain high levels of survival at age 33.

**Black Spruce**

Survival = 68.45 + 0.50*MAT - 0.21 MAT^2; R^2 = 0.03

Data Credit: William Parker, Lakehead University
AM-related Research
- Survival Functions, Cont’d -

- Have explored the relationship for 7 species in total (Pl, Sb, Pj, Sw, Plob, Fd, and Cy)

- Movements of 4-5 C or more are required for survival to drop by >10%

- Relationships are consistently weak (R² < 0.10)

- Overall, preliminary results suggest that survival may not be a large concern for AM movements

- White Spruce
  Survival = 79.31 + 1.41*MAT - 0.09*MAT²; R² = 0.02

- Jack Pine
  Survival = 78.96 + 0.52*MAT - 0.39*MAT²; R² = 0.02
AM-related Research
- Survival Functions, Cont’d -

- Ongoing work looking at best approach for analyzing and presenting the survival relationships
- Exploring approaches similar to URF in which survival rates for any seed source can be estimated for any planting site
- Survival data (0,1) is well suited to a logistic regression approach
Assisted Migration

– Take-home Messages –

- Assisted migration is a nuanced concept that involves more than just moving species to new locations.
- Forestry offers an opportunity to practice a unique flavour of assisted migration.
- Several Canadian provinces are moving ahead with plans to incorporate AM into seed transfer; related tools are being developed.
- URFs can help to identify suitable seed sources for planting under climate change based on expected growth rates.
- Range position considerations offer another low risk option for incorporating CC resilience into forest regeneration/restoration efforts.
- Early findings suggest that survival may be a relatively minor concern for AM-related seed movements.