Maximizing Wood Fibre Growth and Quality in a Changing Climate

Jim Stewart and Isabelle Duchesne
Research Scientists
Canadian Wood Fibre Centre
March 20, 2018

2017-18 CIF e-Lecture Series
“Innovative Solutions to Respond to the Challenge of a Changing Climate”
Collaborative Research Project 1.1

“Wood Characterization for Optimal End-Uses”


• Partners: FPInnovations, UNBC, U Alberta, FGRoW, U Laval, UQAT
CRP 1.1
Themes

- WFA variation and measurement; connections along the value chain
- Linking WFA knowledge and models with operational tools
- Climate influence on wood density and other WFA

Silviculture effects on WFA

* WFA = wood and fibre attributes
CRP 1.1 Themes

Climate influence on wood density and other WFA

* WFA = wood and fibre attributes
Climate influence on WFA

Why is it important?
• Right scale,
• Right place,
• Right price

Technical challenges
➢ Tools from dendrochronology
Climate Influence on WFA

• How can we use these models?

Looking back
• Use past climate to re-construct wood production
• Estimate wood properties in forest inventories

Looking forward
• Use climate projections to predict effects on wood properties
• Assess climate change effects on wood quality
Studies in Eastern Canada
Maximizing Wood Fibre Growth and Quality in a Changing Climate!

Geographical variation in tree and wood characteristics and lumber quality of plantation-grown spruces (ongoing study)

Isabelle Duchesne, Patrick Lenz, Martin Girardin, Johann Housset, Nathalie Isabel, Julien Beguin, Sébastien Clément, Marie Deslauriers, Daniel Plourde, Peter Arbour

Collaborators: L. Bédard and F. Tanguay (FPInnovations), L.-F. Daigle (INRS)

Two objectives

1. Evaluate the influence of climate variables on growth and wood density in white spruce (dendroclimatology)

2. Evaluate the quality of lumber products from different seed sources (mature provenance trials) along a geographical gradient
Maximizing Wood Fibre Growth and Quality in a Changing Climate!

Research Team

Isabelle Duchesne
Silviculture/ Lumber quality

Martin Girardin
Forest Productivity/ Dendroclimatology

Nathalie Isabel
Tree Genetics/ Adaptation

Julien Beguin
Statistical analysis

Patrick Lenz
Tree Genetics/ Wood quality traits

Johann Housset
Dendroclimatology
CFS Common garden: a tool to inform on tree responses to climate change

We need information on the consequences of moving tree populations along climatic gradients.

- Moving a provenance to a warmer site may help anticipate the effect of warming.
- Moving a provenance to a colder site informs on the possible response of a population transferred to colder conditions in the context of climate change.
Common gardens (provenance trial E-194) established by the CFS in 1963-64

14 seed sources (provenances)
378 increment cores sampled at DBH
(3 sites x 3 blocks/site x 14 prov. x 3 trees/prov.)
1.8 m initial spacing
Tree age: 56
Maximizing Wood Fibre Growth and Quality in a Changing Climate

Preliminary results: Correlation BAI - Temperature

- **Basal Area Increment**

- **Petawawa site (South):** negative correlation between BAI and the mean monthly temperature in the month of September preceding ring formation

- **St-Jacques site:** June temperature of current growth year has a negative effect on the BAI

- **Baskatong (North):** weaker correlations

### Correlation between BAI and mean monthly temperature (1980 – 2014 period)

<table>
<thead>
<tr>
<th>Prov.#</th>
<th>Correlation Coefficient</th>
<th>Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petawawa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D 2604</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>D 2486</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>D 2484</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>D 2472</td>
<td>1.8</td>
<td>2.2</td>
</tr>
<tr>
<td>D 2480</td>
<td>2</td>
<td>2.2</td>
</tr>
<tr>
<td>D 2447</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>D 2491</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>D 2454</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>D 2473</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>D 2464</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>D 2603</td>
<td>6</td>
<td>6.2</td>
</tr>
<tr>
<td>D 2445</td>
<td>6.6</td>
<td>6.6</td>
</tr>
</tbody>
</table>

| Baskatong    |                          |         |
| H 2486       | 0.9                      | 0.9     |
| H 2484       | 1.5                      | 1.5     |
| H 2472       | 1.8                      | 2.2     |
| H 2480       | 2                        | 2.2     |
| H 2447       | 2.6                      | 2.6     |
| H 2491       | 2.8                      | 2.8     |
| H 2454       | 3.5                      | 3.5     |
| H 2473       | 4.6                      | 4.6     |
| H 2464       | 5.2                      | 5.2     |
| H 2603       | 6.6                      | 6.6     |
| H 2445       | 6.6                      | 6.6     |

| St-Jacques   |                          |         |
| I 2604       | 0.9                      | 0.9     |
| I 2486       | 1.5                      | 1.5     |
| I 2484       | 1.5                      | 1.5     |
| I 2472       | 1.8                      | 2.2     |
| I 2480       | 2.2                      | 2.2     |
| I 2447       | 2.6                      | 2.6     |
| I 2491       | 2.8                      | 2.8     |
| I 2454       | 3.5                      | 3.5     |
| I 2473       | 4.6                      | 4.6     |
| I 2464       | 5.2                      | 5.2     |
| I 2603       | 6.6                      | 6.6     |
| I 2445       | 6.6                      | 6.6     |

**Legend:**
- Red: Positive correlation
- Green: Negative correlation

**Correlation Coefficient:**
- 0.8 to 1: Strong positive correlation
- 0.0 to 0.2: Weak positive correlation
- -0.2 to 0.0: Weak negative correlation
- -0.8 to 0.8: Strong negative correlation
Preliminary results: Correlation BAI - Temperature

- Basal Area Increment

  - At each site, the local provenance (adapted) did not grow differently compared to the remote provenances

  - Site effect more important that the provenance for the BAI response to monthly temperature (period 1980-2014)

* = local provenance
**Correlations - Ring density vs. mean monthly temperature**

- **For Baskatong only:**
  - Negative correlation between ring density and September temperature the year preceding ring formation

- **For the 3 sites:**
  - Strong positive correlation between density and MAY temperature in the current year of ring formation
  - No clear provenance effect on wood density

* = local provenance
Our preliminary results indicate that sites have more effects than provenances on tree-ring growth (BAI) and density. However we do not have extremes from the entire white spruce distribution area.
Would assisted migration within the eastern region have any effect on lumber quality?

Are there any differences between provenances and sites in terms of:

- lumber stiffness (MOE) and strength (MOR)
- lumber density
- lumber visual grades (NLGA)?

Baskatong (MAT: 2.8 °C) vs. Petawawa (MAT: 4.6 °C)

**Range** of mean annual temperatures (MAT) of the 6 provenances (from Thunderbay to Edmundston): 1.8 to 6.0 °C
Maximizing Wood Fibre Growth and Quality in a Changing Climate

Study Approach

<table>
<thead>
<tr>
<th>Sites</th>
<th>Provenances</th>
<th>Trees</th>
<th>Logs</th>
<th>Lumber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baskatong (north)</td>
<td>6</td>
<td>54</td>
<td>161</td>
<td>331</td>
</tr>
<tr>
<td>Petawawa (south)</td>
<td>6</td>
<td>54</td>
<td>223</td>
<td>612</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>108</strong></td>
<td><strong>384</strong></td>
<td><strong>943</strong></td>
<td></td>
</tr>
</tbody>
</table>

Canadian Wood Fibre Centre
Creating sustainable forest solutions

Natural Resources Canada
Ressources Canada

Canada
Results – Average volume of No.2 & better grades produced per tree

54 trees harvested per site
9 trees per provenance

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>numDF</th>
<th>ddf</th>
<th>SS-1-2</th>
<th>ddf</th>
<th>3-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>92</td>
<td>&lt;.0001</td>
<td>47</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Site</td>
<td>1</td>
<td>4</td>
<td>0.0029</td>
<td>4</td>
<td>0.1654</td>
</tr>
<tr>
<td>Provenance</td>
<td>5</td>
<td>92</td>
<td>0.0239</td>
<td>47</td>
<td>0.328</td>
</tr>
<tr>
<td>Site x Provenance</td>
<td>5</td>
<td>92</td>
<td>0.1848</td>
<td>47</td>
<td>0.7382</td>
</tr>
</tbody>
</table>
Results – No significant effect of site or provenance on lumber stiffness (MOE)

Mean annual temp. range of the 6 provenances 1.8 to 6.0 °C

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>numDF</th>
<th>denDF</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>92</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Site</td>
<td>1</td>
<td>4</td>
<td>0.0901</td>
</tr>
<tr>
<td>Provenance</td>
<td>5</td>
<td>92</td>
<td>0.1313</td>
</tr>
<tr>
<td>Site x Provenance</td>
<td>5</td>
<td>92</td>
<td>0.7433</td>
</tr>
</tbody>
</table>

Max delta MAT:
- Baskatong = -3.2 °C #2467, LacMiller, ON
- Petawawa = +2.8 °C; #2473, Edmundston

BaskQC-PetawON-LacMillerON-PriceQC-EdmNB-KakaFallsON
Results - No significant effect of site or provenance on lumber strength (MOR)

Mean annual temp. range of the 6 provenances: 1.8 to 6.0 °C
Summary – Lumber quality (objective 2)

• Better individual tree growth in Petawawa (2 fold, thinning) than in Baskatong

• Lumber quality did not vary much between sites and provenances at the end of the rotation (age 56).

• Next steps will be to compare the knottiness pattern of trees using CT-Scan technology (ongoing)
Modelling the effect of climatic variables on wood density in spruce

- Alexis Achim (PI) and Mariana Hassegawa
- Laval University
- Models linking wood properties to cambial age (Sattler and Stewart 2016), height along the stem (Kuprevicius et al. 2013), site characteristics (Auty and Achim 2008), etc. are able to explain ~50% of the variance
- Part of the residual variation is linked to the interactive effects of climatic variables and other important environmental drivers
Challenges:

- High collinearity among climate variables
- Difference in time scale between climate variables and growth rings data
Study approach

• Black spruce trees sampled near Chibougamau, QC
• Establish correlation between wood density and $\delta^{13}$C and $\delta^{18}$O isotopes within annual growth rings
• Investigate the effects of drought periods on wood density using isotopes as proxy
Ongoing study

Rings selected based on available climate data

2004 - 2010

Rings were separated with a microtome into three parts

α-cellulose extracted for isotope analysis
Application

• The described approach will help to establish correlations between wood density and climate variables at a smaller time scale
• This study will further knowledge about the influence of drought periods on wood density
Can Silviculture Solutions Mitigate Timber Supply Impacts Resulting From Climate Change - CIF e-Lecture

Studies in Western Canada

[Map of Canada with Western provinces highlighted]
Climate, location, and growth relationships with wood stiffness and wood density at the site, tree, and ring levels in white spruce (Picea glauca) in the Boreal Plains ecozone

Researchers:

James D. Stewart, Canadian Wood Fibre Centre (CWFC)
Cyriac Mvolo, Canadian Wood Fibre Centre (CWFC)
Derek Sattler, B.C. Ministry of Forests, Lands and Natural Resource Operations
Ahmed Koubaa, Université du Québec en Abitibi-Témiscamingue (UQAT)

Partners: fRI, UQAT
Little information on climate/location effects on modulus of elasticity (MOE) and wood density (RD) in white spruce (Sw), especially in the Boreal Plain Ecozone (BPE).

Objectives:

1. Examine the relationship between wood stiffness / wood density, radial growth, climate, and geographic location within the Boreal Plains ecozone from the juvenile and mature wood sections of spruce trees.

2. Develop and validate the use of a nonlinear mixed-effects models for the prediction of the radial profile of wood stiffness and wood density for use in the Boreal Plains ecozone.
Can Silviculture Solutions Mitigate Timber Supply Impacts Resulting From Climate Change - CIF e-Lecture

- 3 datasets
- 24 sites
- 303 trees
- 21720 = 4344 5-years SilviScan MOE/RD
- 891 weather stations
- 33 climatic variables (BioSim), from 1901 to 2010
- 3 location variables were assessed

\[
\text{MOE}_{ijk} = \gamma_0 + c_{0.j} + c_{0.ij} + \gamma_3 \text{Elevation} \times \exp \left( -\frac{\gamma_1}{\text{Ring}_{ijk}} \right) + \gamma_2 + \gamma_4 \text{RA} + \gamma_5 \text{WB}_{\text{sum}} + \epsilon_{ijk}
\]

\[
\text{RD}_{\text{ring},\beta} = \beta_{01} + c_{0.j} + c_{0.ij} + \beta_{02} \text{RW} + \beta_{03} \text{Elevation} + \beta_{04} \text{WB}_{\text{sum}} + \beta_{05} \text{CDD0}_{\text{sum}} + \frac{\beta_{1} - \beta_{0}}{1 + e^{\frac{\beta_{1} - \beta_{0}}{\beta_{3}}}} \text{Ring}_{ijk} + \epsilon_{ijk}
\]

- LOOCV; PRESS, RMSE, $R^2$
Can Silviculture Solutions Mitigate Timber Supply Impacts Resulting From Climate Change - CIF e-Lecture

<table>
<thead>
<tr>
<th>Climate variable</th>
<th>Juvenile wood MoE_L</th>
<th>Mature wood MoE_L</th>
</tr>
</thead>
<tbody>
<tr>
<td>t value</td>
<td>Correlation</td>
<td>t value</td>
</tr>
<tr>
<td>PET_{spring}</td>
<td>2.10</td>
<td>0.41</td>
</tr>
<tr>
<td>WB_{spring}</td>
<td>-2.30</td>
<td>-0.44</td>
</tr>
<tr>
<td>WB_{sum}</td>
<td>-2.13876</td>
<td>-0.41</td>
</tr>
<tr>
<td>WR_{sum}</td>
<td>-2.34203</td>
<td>-0.44</td>
</tr>
<tr>
<td>CDD_{sum}</td>
<td>-2.75241</td>
<td>-0.50</td>
</tr>
<tr>
<td>WB_{fall}</td>
<td>-2.337</td>
<td>-0.44</td>
</tr>
<tr>
<td>WR_{fall}</td>
<td>-2.37695</td>
<td>-0.45</td>
</tr>
<tr>
<td>PET_{fall}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WB_{fall}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tmin_{fall}</td>
<td>3.940594</td>
<td>0.68</td>
</tr>
<tr>
<td>Tmax_{fall}</td>
<td>4.289628</td>
<td>0.71</td>
</tr>
<tr>
<td>PET_{fall}</td>
<td>4.289628</td>
<td>0.71</td>
</tr>
<tr>
<td>CDD_{fall}</td>
<td>-2.49828</td>
<td>-0.50</td>
</tr>
</tbody>
</table>

Site location / Climate effect | Mean | Ring-group-level |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ring density</td>
</tr>
<tr>
<td>Ring density</td>
<td>452.3</td>
<td>1</td>
</tr>
<tr>
<td>Ring width</td>
<td>1.34</td>
<td>-0.41</td>
</tr>
<tr>
<td>Elevation</td>
<td>852.3</td>
<td>-0.22</td>
</tr>
<tr>
<td>Longitude</td>
<td>-113.4</td>
<td>0.12</td>
</tr>
<tr>
<td>Latitude</td>
<td>54.5</td>
<td>0.03</td>
</tr>
<tr>
<td>PET</td>
<td>84</td>
<td>0.20</td>
</tr>
<tr>
<td>WB</td>
<td>-14.4</td>
<td>-0.18</td>
</tr>
<tr>
<td>WR</td>
<td>0.85</td>
<td>-0.18</td>
</tr>
<tr>
<td>Tmin</td>
<td>5</td>
<td>0.18</td>
</tr>
<tr>
<td>Tmax</td>
<td>18.2</td>
<td>0.25</td>
</tr>
<tr>
<td>Prec</td>
<td>69.6</td>
<td>-0.10</td>
</tr>
<tr>
<td>Tavg</td>
<td>11.7</td>
<td>0.22</td>
</tr>
<tr>
<td>Psea</td>
<td>1.9</td>
<td>0.10</td>
</tr>
<tr>
<td>GDD5</td>
<td>211.4</td>
<td>0.22</td>
</tr>
<tr>
<td>CDD0</td>
<td>0.75</td>
<td>-0.10</td>
</tr>
<tr>
<td>Tsea</td>
<td>0.33</td>
<td>-0.09</td>
</tr>
</tbody>
</table>
### Can Silviculture Solutions Mitigate Timber Supply Impacts Resulting From Climate Change - CIF e-Lecture

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_0$</td>
<td>12.98</td>
<td>0.4438</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>15.47</td>
<td>0.3790</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>7.27</td>
<td>0.1176</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\gamma_3$ (Elevation)</td>
<td>-0.004</td>
<td>0.0004</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\gamma_4$ (RA)</td>
<td>-0.002</td>
<td>0.0001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>$\gamma_5$ (WB&lt;sub&gt;sum&lt;/sub&gt;)</td>
<td>-0.002</td>
<td>0.0010</td>
<td>0.003</td>
</tr>
</tbody>
</table>

#### Random effects

- $c_{0,j}$ (site): 0.4305
- $c_{0,ij}$ (tree in site): 1.3224
- Residuals: 1.8451

#### Final model fit statistics

- $R^2$ fixed: 58%
- $R^2$ fixed + random: 69%
- Bias: 0.09
- $|E|$% ring group 0–30: 16.61
- $|E|$% ring group 30–50: 12.38
- $|E|$% ring group > 50+: 12.56
- RMSE: 2.05
- SSE: $1.97 \times 10^4$
- PRESS: $2.00 \times 10^4$
- Cross-validation $R^2$: 57%
Key results

**MOE**
- MOE decrease with growth rate
- MOE vary between study sites
- Summer variables are the most useful climate variables
- Water regime has more influence in MOE than temperature regime
- Random effects account for a significant part of the variation
- MOE affected by different factors in juvenile and mature wood

**RD**
- RD decrease with growth rate
- RD vary between study sites
- Summer variables are the only useful climate variables
- Water regime has more influence in RD than temperature regime
- Random effects account for up to half of the explained variation
Practical implication: Development of a practical models to predict modulus of elasticity and wood density across the BPE using a wide range of climate and location variables.

Limit: Models developed using only dominant and codominant trees.

Conclusion:

It is possible to predict modulus of elasticity and wood density of a broad geographical area using growth rate, location and climate. Random effects may account for up to half of the prediction power, and must be accounted for.
Linking WFA knowledge and models with operational tools

- WQ4MGM: software module for Mixedwood Growth Model
Fibre properties related to value, disease, climate and genetics in Douglas-fir

• Mike Cruikshank, Cosmin Filipescu
• Partners: BC MOF genetics
• Study rationale: Little is known about how conifers respond to disease and how this affects fibre properties
• Objectives: To understand genetic control of disease through resistance and tolerance and to link these to fibre properties, drought, and wood quality
Fibre properties related to value, disease, climate and genetics in Douglas-fir
**Genetics**

5 half-sibling families

Inoculated with Armillaria root disease

FAMILY LEVEL

Wood density increased with disease and summer precipitation

- allows tree to grow later in the year when latewood formed
**Wood Density**

- Biggest change = root disease

Affected by:
- Tracheid wall thickness
- Tracheid diameter
- Proportion of earlywood to latewood

Purpose: to prevent cavitation
Sharp density transitions cause warp

- Disease causes differential shrinkage rates between areas
- Climate affects density less than disease - fluctuation rather than a state shift
- Control disease through site prep, species, or genotype selection
Can Silviculture Solutions Mitigate Timber Supply Impacts Resulting From Climate Change - CIF e-Lecture

Evaluating hardwood fibre attributes across ecological and latitudinal gradients in north central B.C

Dr. Che Elkin, Dr. Lisa Wood

• Study Rationale
  • Advancement and diversification of hardwood-based products in western Canada requires an improved understanding of hardwood fibre attributes, regional variation in hardwood fibre traits, and how hardwood fibre attributes are influenced by growing conditions

• Objectives
  • Characterize a range of wood and fibre attributes, and evaluate the relative influence of stand composition and geographic location on hardwood characteristics
Study approach

• 5 sampling locations in the B.C. interior
  • Sites selected to cover temperature and precipitation gradients
  • At each site, increment cores taken from aspen growing in mixedwood (N = 15) and pure (N = 15) stands
  • Stand and tree-neighborhood conditions characterized

• Measured annual growth, wood density, cell wall thickness, radial and tangential cell diameters and microfibril angle

• Wood and fibre attributes analyzed with respect to region, stand composition, and neighborhood competitive environment
Key result

- Wood characteristics and fibre attributes differ:
  - Geographically
  - Between mixed and pure stands

- Magnitude of the geographic differences, and stand composition impacts, varies considerably between measured fibre attributes

- High within stand variation for all fibre attributes
Key result

• Changes in wood and fibre attributes as trees grow differs between regions and between pure and mixed stands

• Initial results suggest that the impact of stand and tree-neighborhood conditions on fibre attributes differ between regions
Application

• Our work improves our understanding of how climate, site conditions, and forest management practices, interact to influence hardwood quality and wood fibre attributes

• Our results can contribute to:
  • An increase in hardwood utilization and the efficient development of hardwood forest products
  • Retention of hardwoods on the landscape, and the associated ecosystem and social benefits
  • Improved hardwood and mixedwood management

Dr. Lisa Wood in a pure aspen stand at our central site
Climate influence on WFA

- This knowledge will help manage current forests, and assess risks to future forests
- Scope of work is national
- Focus on commercial tree species, softwood and hardwood
- Important attributes measured: annual growth, wood density, cell dimensions, MoE, MFA
- Forward-looking
Questions?

• Contact info
  • Isabelle.Duchesne@Canada.ca
  • Jim.D.Stewart@Canada.ca

• Key links
  • http://www.nrcan.gc.ca/forests/research-centres/cwfc/13457