Mapping model of wood quality characteristics of black spruce (*Picea mariana* (Mill.) B.S.P.) in Northern Ontario

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# Outline

| Background | Site Productivity and Ecological Land Classification System  
Predicting value – wood quality |
|------------|--------------------------------------------------------------------------------------------------|
|            | Data collection and processing  
Juvenile and mature wood demarcation  
Correlation between wood quality attributes and site, tree and stand and LiDAR derived variables  
A predictive mapping model of wood quality attributes – e.g. wood density |
| Conclusion | Application – value-based optimization  
Competitive forest industry |
### Forest site productivity

<table>
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<tr>
<th>Approaches</th>
<th>Origin</th>
<th>Spatial Context</th>
<th>Stability</th>
<th>Primary Application</th>
<th>Driving Variables</th>
<th>Targeted Structure and Composition</th>
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<tbody>
<tr>
<td>Phytocentric</td>
<td>1920s</td>
<td>Local Stand level</td>
<td>Static Remains constant over time</td>
<td>Timber production</td>
<td>Effects</td>
<td>Even-aged single species stand</td>
</tr>
<tr>
<td>Geocentric</td>
<td>1960s</td>
<td>Regional Landscape level</td>
<td>Dynamic Changes gradually with the driving variables</td>
<td>Landscape level planning</td>
<td>Causes</td>
<td>Bare land or forested landscape</td>
</tr>
<tr>
<td>Phytogeocentric</td>
<td>1960s</td>
<td>Hierarchical Integrated from stand to landscape</td>
<td>Dynamic Units remain stable for 20-40 years</td>
<td>Ecosystem management</td>
<td>Causes and effects</td>
<td>Substrate that is suitable for plant growth and development</td>
</tr>
</tbody>
</table>

(Pokharel and Dech 2011)
**Ecosites** are elements of the ecosystem classification framework that stratify the forest landscape into ecologically constructed polygons (Pokharel et al. 2012).

### Substrate Characteristics
- **Substrate (mineral or organic)**
  - Very Shallow Dry to Fresh to Humid Ecosites
  - Dry Sandy Ecosites
  - Fresh Sandy or Dry to Fresh Coarse Loamy Ecosites
  - Moist Sandy to Coarse Loamy Ecosites
  - Fresh Clayey Ecosites
  - Fresh Silty to Fine Loamy Ecosites
  - Moist Silty to Fine Loamy to Clayey Ecosites
  - Hydric Ecosites

### Canopy Composition and Dominance

#### Conifer (1-6)
1. Red Pine-White Pine Conifer
   - (Pr +/Pw ≥20% of absolute cover)
2. Black Spruce-Jack Pine Dominated Conifer
   - (Sb +/ Pf) +/ Bw ≥90% (Bw ≤20%)
3. Pine-Black Spruce Conifer
   - (Sb +/ Pf ≥50% of conifer cover)
4. Cedar-Hemlock Conifer
   - (Ce +/ He ≥50% of conifer cover)
5. Spruce-Fir Conifer
   - (Bf +/ Sx ≥50% of conifer cover)
6. Conifer (Conifer mixture)
   - White Pine Mixedwood
     - (Pw ≥20% of absolute cover)
   - Red Pine-White Pine Mixedwood
     - (Pr + Pw ≥30% of absolute cover)
   - Aspen-Birch Hardwood
     - (Po + Bx ≥50% of hardwood cover)
7. Elm-Ash Hardwood
   - (Ew + Ax ≥50% of hardwood cover)
8. Oak Hardwood
   - (Ox ≥50% of hardwood cover)
9. Sugar Maple Hardwood
   - (Mh ≥50% of hardwood cover)
10. Red Maple Hardwood
    - (Mr ≥50% of hardwood cover)
11. Maple Hardwood
    - (Mx ≥50% of hardwood cover)
12. Rich Conifer Swamp
    - (Cw +/ He ≥50%, / ≥2 rich swamp indicators)
13. Intermediate Conifer Swamp
    - (La ≥10%, +/ alder ≥10% / ≥2 intermediate/rich swamp indicators)
14. Poor Conifer Swamp
    - (Bf ≥90%, + ≥2 swamp indicators / alder present)
15. Tree Bog
    - (Bf ≥90%, trees >10 m tall are ≤25% and hydrologically isolated)
16. Intolerant Hardwood Swamp
    - (Po + Ax ≥50% of hardwood cover)
17. Intolerant Hardwood Swamp
    - (Mx ≥50% of hardwood cover)
18. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)
19. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)

#### Hardwood (7-15)
10. Elm-Ash Hardwood
    - (Ew + Ax ≥50% of hardwood cover)
11. Oak Hardwood
    - (Ox ≥50% of hardwood cover)
12. Sugar Maple Hardwood
    - (Mm ≥50% of hardwood cover)
13. Red Maple Hardwood
    - (Mr ≥50% of hardwood cover)
14. Maple Hardwood
    - (Mx ≥50% of hardwood cover)
15. Mixedwood
    - (Mixed hardwood)
16. Rich Conifer Swamp
    - (Cw +/ He ≥50%, / ≥2 rich swamp indicators)
17. Intermediate Conifer Swamp
    - (La ≥10%, +/ alder ≥10% / ≥2 intermediate/rich swamp indicators)
18. Poor Conifer Swamp
    - (Bf ≥90%, + ≥2 swamp indicators / alder present)
19. Tree Bog
    - (Bf ≥90%, trees >10 m tall are ≤25% and hydrologically isolated)
20. Intolerant Hardwood Swamp
    - (Po + Ax ≥50% of hardwood cover)
21. Intolerant Hardwood Swamp
    - (Mx ≥50% of hardwood cover)
22. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)
23. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)

#### Hardwood (16-19)
16. Rich Conifer Swamp
    - (Cw +/ He ≥50%, / ≥2 rich swamp indicators)
17. Intermediate Conifer Swamp
    - (La ≥10%, +/ alder ≥10% / ≥2 intermediate/rich swamp indicators)
18. Poor Conifer Swamp
    - (Bf ≥90%, + ≥2 swamp indicators / alder present)
19. Tree Bog
    - (Bf ≥90%, trees >10 m tall are ≤25% and hydrologically isolated)
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    - (Mx ≥50% of hardwood cover)
22. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)
23. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)

#### Hardwood (20-23)
20. Intolerant Hardwood Swamp
    - (Po + Ax ≥50% of hardwood cover)
21. Intolerant Hardwood Swamp
    - (Mx ≥50% of hardwood cover)
22. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)
23. Oak Hardwoods Swamp
    - (Ox ≥50% of hardwood cover)
Site differences

B128: Intermediate Conifer Swamp

B065: Moist Sandy to Coarse Loamy: Black Spruce - Pine
Site effects – Ecosite effects for black spruce

(Pokharel and Dech 2012)
The research interests

- Application of ecological classification system in operational forest management
- Fibre attributes are key variables in market based value-chain optimization tools in forestry (Li 2009; Watson and Bradley 2009).
- Developing a predictive model of wood fibre properties for a large scale forest management planning is important in Ontario
Objectives

- To quantify the relationships between wood quality attributes (e.g., density, earlywood–latewood ratio (expressed as latewood percentage), microfibril angle (MFA), modulus of elasticity (MOE)) and ecological land classification (ELC) variables (e.g., ecosite) and other tree- and stand-level variables for black spruce in the northeastern boreal forest of Ontario,

- To develop a classification model that could be applied to predict and map average tree-level fibre quality attributes for black spruce within forest resources inventory polygons on a representative forest management unit.
Boreal region of Ontario
Boreal forest
Data collection and processing

- Stratified random sampling using Geospatial Modelling Environment (formerly known as Hawth’s Analysis Tool for ArcGIS)
- Establish plot, measure tree and stand level variables
- Field ecosite typing using Ecological Land Classification field manual 2009
- Extract 12 mm core from three randomly selected co-dominant/dominant trees from the plot
- Cores were stored, processed and analyzed using SilviScan technology
Wood density varies by earlywood and latewood ecosite groups.

### Latewood basal area (mm²)

<table>
<thead>
<tr>
<th>Ecosite groups</th>
<th>n trees</th>
<th>n rings</th>
<th>Mork Index</th>
<th>Inflection Point</th>
<th>WinDendro (x=70)</th>
<th>Threshold Value (SG = 0.540)</th>
<th>SilviScan</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Dry_Sandy</td>
<td>5</td>
<td>233</td>
<td>6665.25</td>
<td>13888.32</td>
<td>14497.81</td>
<td>18169.67</td>
<td>11775.00</td>
</tr>
<tr>
<td>3-Dry-Fresh_CoarseLoamy</td>
<td>10</td>
<td>412</td>
<td>12112.39</td>
<td>27991.35</td>
<td>31684.05</td>
<td>35257.75</td>
<td>25571.62</td>
</tr>
<tr>
<td>4-Moist_SandyCoarseLoamy</td>
<td>8</td>
<td>359</td>
<td>11296.16</td>
<td>27427.03</td>
<td>31119.08</td>
<td>34559.72</td>
<td>25196.27</td>
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<tr>
<td>5-Fresh_Clay</td>
<td>7</td>
<td>326</td>
<td>9733.30</td>
<td>17348.02</td>
<td>17538.63</td>
<td>24520.67</td>
<td>14527.65</td>
</tr>
<tr>
<td>6-Fresh_Silty_FineLoamy</td>
<td>10</td>
<td>418</td>
<td>12854.32</td>
<td>33799.15</td>
<td>38985.89</td>
<td>41239.33</td>
<td>31819.99</td>
</tr>
<tr>
<td>7-Moist_Silty_FineLoamy_Clay</td>
<td>26</td>
<td>1192</td>
<td>38918.06</td>
<td>86094.88</td>
<td>97377.02</td>
<td>112767.62</td>
<td>78923.70</td>
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<tr>
<td>8-Swamps.Intermediate</td>
<td>23</td>
<td>1062</td>
<td>26772.31</td>
<td>50678.96</td>
<td>51556.29</td>
<td>73311.46</td>
<td>42805.26</td>
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<tr>
<td>8-Swamps_Poor</td>
<td>30</td>
<td>1385</td>
<td>30541.42</td>
<td>56811.04</td>
<td>56108.09</td>
<td>83444.09</td>
<td>46766.99</td>
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<tr>
<td>8-Swamps_Rich</td>
<td>14</td>
<td>634</td>
<td>15788.35</td>
<td>35564.93</td>
<td>37773.97</td>
<td>52064.11</td>
<td>30812.52</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>133</strong></td>
<td><strong>6021</strong></td>
<td><strong>164681.56</strong></td>
<td><strong>349603.67</strong></td>
<td><strong>376640.81</strong></td>
<td><strong>475334.43</strong></td>
<td><strong>308199.00</strong></td>
</tr>
</tbody>
</table>
Proportion of earlywood and latewood in a ring profile truncated to first 50 years

Radial width (mm) vs. Rings from pith
The conceptual link to wood quality

Growth Rate

Ecosite

Fibre Attributes

Mature
Immature
Juvenile

Year
Comparative analysis of wood fibre attributes and transition years among four contrasting ecosite groups

(Pokharel et al. 2014)
Comparison of wood quality attributes at reference age of 50 years at breast height for sample tree population representing black spruce

(Pokharel et al. 2014)
Correlation between selected predictor variables and wood density

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Unit</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>Density</td>
<td>kg. m⁻³</td>
<td>537.33</td>
<td>49.90</td>
<td>387.60</td>
<td>669.90</td>
<td>1</td>
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<tr>
<td>MFA</td>
<td>Microfibril angle</td>
<td>degree</td>
<td>12.81</td>
<td>3.12</td>
<td>8.70</td>
<td>23.30</td>
<td>-0.06</td>
</tr>
<tr>
<td>MOE</td>
<td>Modulus of elasticity</td>
<td>GPa</td>
<td>14.89</td>
<td>2.45</td>
<td>7.60</td>
<td>20.50</td>
<td>0.48</td>
</tr>
<tr>
<td>C</td>
<td>Coarseness</td>
<td>µg.m⁻¹</td>
<td>375.28</td>
<td>38.51</td>
<td>274.30</td>
<td>490.60</td>
<td>0.58</td>
</tr>
<tr>
<td>WT</td>
<td>Wall thickness</td>
<td>µm</td>
<td>2.64</td>
<td>0.26</td>
<td>1.94</td>
<td>3.27</td>
<td>0.91</td>
</tr>
<tr>
<td>RD</td>
<td>Radial diameter</td>
<td>µm</td>
<td>27.62</td>
<td>1.43</td>
<td>24.20</td>
<td>31.90</td>
<td>-0.39</td>
</tr>
<tr>
<td>TD</td>
<td>Tangential diameter</td>
<td>µm</td>
<td>26.39</td>
<td>1.37</td>
<td>23.80</td>
<td>30.40</td>
<td>-0.12</td>
</tr>
<tr>
<td>SSA</td>
<td>Specific surface area</td>
<td>m², kg⁻¹</td>
<td>300.71</td>
<td>27.68</td>
<td>246.50</td>
<td>385.70</td>
<td>-0.87</td>
</tr>
<tr>
<td>Topht</td>
<td>Top height</td>
<td>M</td>
<td>17.77</td>
<td>3.62</td>
<td>9.00</td>
<td>25.90</td>
<td>-0.45</td>
</tr>
<tr>
<td>BA</td>
<td>Stand basal area</td>
<td>m². ha⁻¹</td>
<td>27.40</td>
<td>10.34</td>
<td>1.68</td>
<td>51.42</td>
<td>-0.27</td>
</tr>
<tr>
<td>dbhq</td>
<td>Quadratic mean diameter</td>
<td>cm</td>
<td>16.66</td>
<td>3.84</td>
<td>11.08</td>
<td>28.28</td>
<td>-0.48</td>
</tr>
<tr>
<td>TPH</td>
<td>Tree per hectare</td>
<td>#</td>
<td>1,324.08</td>
<td>577.49</td>
<td>175.11</td>
<td>2,601.74</td>
<td>0.12</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf area index</td>
<td>-</td>
<td>2.54</td>
<td>0.78</td>
<td>0.41</td>
<td>4.54</td>
<td>0.49</td>
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<tr>
<td>VCI</td>
<td>Vertical Complexity Index</td>
<td>-</td>
<td>0.68</td>
<td>0.07</td>
<td>0.35</td>
<td>0.81</td>
<td>-0.30</td>
</tr>
<tr>
<td>H</td>
<td>Shannon Weaver Index</td>
<td>-</td>
<td>2.61</td>
<td>0.27</td>
<td>1.37</td>
<td>3.09</td>
<td>-0.32</td>
</tr>
<tr>
<td>P20</td>
<td>Second Decile LiDAR Height</td>
<td>m</td>
<td>0.82</td>
<td>1.20</td>
<td>-</td>
<td>4.02</td>
<td>-0.49</td>
</tr>
<tr>
<td>P60</td>
<td>Sixth Decile LiDAR Height</td>
<td>m</td>
<td>8.13</td>
<td>3.63</td>
<td>0.21</td>
<td>15.38</td>
<td>-0.48</td>
</tr>
<tr>
<td>P80</td>
<td>Eighth Decile LiDAR Height</td>
<td>m</td>
<td>11.41</td>
<td>3.98</td>
<td>1.96</td>
<td>19.58</td>
<td>-0.45</td>
</tr>
<tr>
<td>P90</td>
<td>Ninth Decile LiDAR Height</td>
<td>m</td>
<td>12.97</td>
<td>3.99</td>
<td>3.65</td>
<td>21.53</td>
<td>-0.42</td>
</tr>
<tr>
<td>D1</td>
<td>Cumulative % of the number of returns found in Bin 1 of 10</td>
<td>%</td>
<td>0.32</td>
<td>0.13</td>
<td>0.10</td>
<td>0.70</td>
<td>0.52</td>
</tr>
<tr>
<td>D2</td>
<td>Cumulative % of the number of returns found in Bin 2 of 10</td>
<td>%</td>
<td>0.40</td>
<td>0.13</td>
<td>0.16</td>
<td>0.74</td>
<td>0.49</td>
</tr>
<tr>
<td>D6</td>
<td>Cumulative % of the number of returns found in Bin 6 of 10</td>
<td>%</td>
<td>0.71</td>
<td>0.13</td>
<td>0.47</td>
<td>0.96</td>
<td>0.41</td>
</tr>
<tr>
<td>D7</td>
<td>Cumulative % of the number of returns found in Bin 7 of 10</td>
<td>%</td>
<td>0.81</td>
<td>0.10</td>
<td>0.60</td>
<td>0.98</td>
<td>0.38</td>
</tr>
<tr>
<td>D9</td>
<td>Cumulative % of the number of returns found in Bin 9 of 10</td>
<td>%</td>
<td>0.98</td>
<td>0.02</td>
<td>0.93</td>
<td>0.99</td>
<td>0.21</td>
</tr>
<tr>
<td>DA</td>
<td>First returns/ All Returns</td>
<td>%</td>
<td>77.43</td>
<td>6.37</td>
<td>62.39</td>
<td>94.79</td>
<td>0.35</td>
</tr>
<tr>
<td>cc0</td>
<td>Crown closure &gt; 0 m</td>
<td>%</td>
<td>99.20</td>
<td>1.32</td>
<td>94.85</td>
<td>100.00</td>
<td>-0.22</td>
</tr>
<tr>
<td>cc2</td>
<td>Crown closure &gt; 2 m</td>
<td>%</td>
<td>90.98</td>
<td>10.78</td>
<td>45.00</td>
<td>100.00</td>
<td>-0.46</td>
</tr>
<tr>
<td>cc4</td>
<td>Crown closure &gt; 4 m</td>
<td>%</td>
<td>85.27</td>
<td>15.56</td>
<td>18.00</td>
<td>100.00</td>
<td>-0.45</td>
</tr>
<tr>
<td>cc6</td>
<td>Crown closure &gt; 6 m</td>
<td>%</td>
<td>78.59</td>
<td>19.88</td>
<td>4.00</td>
<td>100.00</td>
<td>-0.44</td>
</tr>
<tr>
<td>cc10</td>
<td>Crown closure &gt; 10 m</td>
<td>%</td>
<td>56.70</td>
<td>29.91</td>
<td>-</td>
<td>100.00</td>
<td>-0.38</td>
</tr>
<tr>
<td>cc12</td>
<td>Crown closure &gt; 12 m</td>
<td>%</td>
<td>41.74</td>
<td>32.60</td>
<td>-</td>
<td>100.00</td>
<td>-0.37</td>
</tr>
<tr>
<td>cc14</td>
<td>Crown closure &gt; 14 m</td>
<td>%</td>
<td>28.86</td>
<td>31.18</td>
<td>-</td>
<td>100.00</td>
<td>-0.32</td>
</tr>
<tr>
<td>cc24</td>
<td>Crown closure &gt; 24 m</td>
<td>%</td>
<td>0.19</td>
<td>0.82</td>
<td>-</td>
<td>4.21</td>
<td>-0.27</td>
</tr>
<tr>
<td>cc26</td>
<td>Crown closure &gt; 26 m</td>
<td>%</td>
<td>0.01</td>
<td>0.10</td>
<td>-</td>
<td>1.05</td>
<td>-0.04</td>
</tr>
</tbody>
</table>
Correlation between selected predictor variables and response variable i.e. wood density
Correlation between selected predictor variables and response variable i.e. wood density

- P20 - Second Decile LiDAR Height (m)
- D2 (Cumulative % of returns in Bin 2 of 10)
- CC2 - Crown closure >2m (%)
- P60 - Sixth Decile LiDAR Height (m)
- First Returns/All Returns (%)
- CC6 - Crown Closure > 6m (%)

Correlation coefficients:
- r = -0.49 (P20 - D2)
- r = 0.49 (D2 - CC2)
- r = -0.46 (CC2 - P60)
- r = -0.48 (P60 - D2)
- r = 0.35 (P20 - CC6)
- r = -0.44 (CC2 - CC6)
Correlation between wood density and latewood percent by ecosite groups

(Pokharel et al. 2014)
Regression Tree model using FRI and LiDAR variables

ELC_Ecosites=degk1nop

ELC_Ecosites=el

Sw.P=2.715

445

474.7

508

P90=16.68

D2=0.395

Ce.P=9.73

LAI=2.035

CrownWidthClass=d

dbhq>=12.63

614.7

614.7

700

600

500

400

Density (Kg.m$^{-3}$)

n= 7

n= 7

n= 15

n= 4

n= 32

n= 23

n= 3

n= 8

n= 4

n= 8
Cross validation of regression tree and variable importance in Random Forests for wood density

\[ r^2 = 74\% \]

\[ r^2 = 41\% \]
Map modelling of wood quality attributes

• Developing a predictive model of wood fibre properties is important for both strategic and tactical forest management planning

• Multi-value forest management

• Fibre – a key variable in market based value-chain optimization
Acknowledgements

Field data collection
  Paul Courville, Shawn Mayhew-Hammond, Elisha Townshend, Jacob McAnney, Scott Perry

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Canadian Wood Fibre Centre
  Guy Smith, Peter Newton

Queens University
  Paul Treitz, Fraser McLeod, Graham Pop

FPInnovations/SilviScan
  Maurice Defo
  Nelson Uy

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