Conifer Biomass Models for the Inland Northwest

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INGY Technical Meeting 2017, Coeur D’Alene, ID
Project goals

1. Develop and apply biomass sampling methods

2. Evaluate existing sources of biomass information
   - Brown '78: Weight and density of crowns of Rocky Mountain conifers
   - Standish et al '85: Development of biomass equations for BC tree species
   - Gray & Reinhardt '03: Analysis of algorithms for predicting canopy fuel

3. Advance new models for estimating conifer biomass
   - tree-level, with components (stem, foliage, etc.)
   - using standard inventory variables (DBH, height, crown length)
Stand & tree selection

- federal, state, tribal, & industrial lands
- no stands treated within 5 years
- trees > 75 ft from road
- tree DBH ≥ 2 inches
- no forked/broken/dead top
- no obvious insect/disease damage
Biomass components

Stem (1’ stump to 2” top)
- Stemwood
- Stembark

Crown (including 2” top)
- Dead branches
- Live branches
  - 1 hour (<0.25”)
  - 10 hour (.25”-1”)
  - 100+ hour (>1”)
- Foliage

From Standish et al 1985
### Other regional data sources

From Brown 1978

<table>
<thead>
<tr>
<th>Table 12.--Raw data for dominants</th>
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<tbody>
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<td><strong>Inches</strong></td>
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<td>209</td>
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</table>

### Summary

- **Douglas-fir**

From Brown 1978
Species-specific component models

\[\text{stemwood mass} = f_1(D, H, L, V)\]
\[\text{stembark mass} = f_2(D, H, L, V)\]
\[\text{foliage mass} = f_3(D, H, L, V)\]
\[\text{dead branch mass} = f_4(D, H, L, V)\]
\[\text{live branch mass} = f_5(D, H, L, V)\]

where

\[D = \text{diameter at breast height}\]
\[H = \text{total height}\]
\[L = \text{live crown length}\]
\[V = \text{Flewelling 2-point volume}\]
Equation forms

Abstract


A review of stem volume and biomass equations for tree species growing in Europe is presented. The mathematical forms of the empirical models, the associated statistical parameters and information about the size of the trees and the country of origin were collated from scientific articles and from technical reports. The total number of the compiled equations for biomass estimation was 607 and for stem volume prediction it was 230.
Equation specification

Two common forms

\[ \text{mass} = b_0 D^{b_1} H^{b_2} L^{b_3} \]
\[ \text{mass} = b_0 D^{b_1} H^{b_2} e^{b_3} L/H \]

Selection criteria:

1. High out-of-sample estimation accuracy
   - assessed via cross-validation

2. Unbiasedness across tree sizes
   - assessed from residual plots
Model assessments

- Summarize accuracy using felled tree data
  - e.g., $R^2$

- Quantitative evaluation against independent tree data
  - crown biomass data collected by RMRS researchers
  - crown and stem biomass data collected in BC

- Qualitative evaluation against existing models
  - Jenkins et al. 2003 national models
  - Forest Inventory & Analysis methodology
## Sample sizes

<table>
<thead>
<tr>
<th>Species</th>
<th>Stands</th>
<th>Trees</th>
<th>Foliage</th>
<th>Live br.</th>
<th>Dead br.</th>
<th>Stem component</th>
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<td>Subalpine fir</td>
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<td>52</td>
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<td>Western larch</td>
<td>18</td>
<td>58</td>
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<td>44</td>
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<td>Engelmann spruce</td>
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<td>Lodgepole pine</td>
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<tr>
<td>Ponderosa pine</td>
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<td>85</td>
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<td>84</td>
<td>81</td>
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<tr>
<td>Douglas-fir</td>
<td>37</td>
<td>92</td>
<td>92</td>
<td>92</td>
<td>88</td>
<td>42</td>
</tr>
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</table>
Geographic distribution
Geographic distribution

- Douglas-fir
- Ponderosa pine
- Lodgepole pine
- Engelmann spruce
- Western larch
- Subalpine fir
- Grand fir

Elevation a.s.l. (ft)

2000 4000 6000 8000
Size distribution

- Lodgepole pine
- Ponderosa pine
- Douglas-fir
- Grand fir
- Subalpine fir
- Western larch
- Engelmann spruce
Western larch models

\[ \text{stemwood mass} = 0.00826 D^{1.76} H^{1.43} \]
\[ \text{stembark mass} = 0.00195 D^{1.63} H^{1.33} \]
\[ \text{foliage mass} = 0.787 + 0.00201 D^{1.28} H^{1.97} L^{0.94} \]
\[ \text{dead branch mass} = 0.0221 D^{0.821} H^{0.669} \]
\[ \text{live branch mass} = 2.14 + 0.000500 D^{1.41} H^{1.13} L^{1.04} \]

where

- \( D \) = diameter at breast height
- \( H \) = total height
- \( L \) = live crown length
Live branch biomass models

With D as sole predictor

With D, H, L as predictors
Live branch biomass distribution
Western larch models

\[ \text{stemwood mass} = 0.00826 D^{1.76} H^{1.43} \]

\[ \text{stembark mass} = 0.00195 D^{1.63} H^{1.33} \]

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where

\[ D = \text{diameter at breast height} \]
\[ H = \text{total height} \]
\[ L = \text{live crown length} \]
Douglas-fir models

\[
\begin{align*}
\text{stemwood mass} &= 0.00987 D^{1.64} H^{1.49} \\
\text{stembark mass} &= 0.00238 D^{1.65} H^{1.26} R^{-0.396} \\
\text{foliage mass} &= 0.00283 D^{2.17} H^{-0.545} e^{1.41R} \\
\text{dead branch mass} &= 0.00095 D^2 H \\
\text{live branch mass} &= 0.0251 D^{2.65} H^{-0.637} e^{0.834R}
\end{align*}
\]

where

\[
\begin{align*}
D &= \text{diameter at breast height} \\
H &= \text{total height} \\
R &= \text{live crown ratio} = \frac{L}{H}
\end{align*}
\]
## Model forms

### Stemwood

<table>
<thead>
<tr>
<th>Source</th>
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<th>Douglas-fir</th>
</tr>
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<tbody>
<tr>
<td><strong>INGY</strong></td>
<td>$\propto D^{1.76} H^{1.43}$</td>
<td>$\propto D^{1.64} H^{1.49}$</td>
</tr>
<tr>
<td><strong>FIA</strong></td>
<td>$\propto D^{1.76} H^{1.28}$</td>
<td>$\propto D^{1.70} H^{1.22}$</td>
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<tr>
<td>Jenkins et al (2003)</td>
<td>$\propto D^{2.26} e^{-1.143/D}$</td>
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### Stembark

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<td>$\propto D^{2.26} e^{-1.806/D}$</td>
<td>$\propto D^{2.44} e^{-1.806/D}$</td>
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Western larch stem mass estimating equations

INGY equation (2 in top)
FIA equations (2 in top)
Jenkins et al. (2003) equation (4 in top)
Tree-level biomass comparisons

Live trees (>5” DBH) on FIA plots ≤60 miles of sample points
Landscape-level biomass comparisons

Live trees (>5” DBH) on FIA plots ≤60 miles of sample points
Summary

1. INGY has developed a dataset of 470 felled trees on 7 species.
2. Biomass equations with D & H (& often L) outperform equations based only on D.
   - constrained combinations of D & H are useful.
3. Considerable unexplained variation in dead branch biomass; considerable variation in stem mass can be explained.
4. Model assessment & validation work continues.
5. Sampling of aspen, hemlock, large trees to continue.
Funding provided by

- Spokane Tribe of Indians
- USDA Forest Service, Northern Region
- Joint Fire Science Program
- USDA Forest Service, Forest Inventory & Analysis