Forest productivity, feedstock removals, and implications for nutrient flux and sustainability

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Productivity tasks

- Task SM-SP-4.2. Estimate nutrient and carbon removals and retention under various levels of biomass harvesting

- Task SM-SP-4.3. Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities
Productivity tasks

• Estimate nutrient and carbon removals and retention under various levels of biomass harvesting
  – Biomass equations & nutrient concentrations
  – Retention and removals during felling and yarding
  – Implications for nutrient retention and removal

• Determine sustainable levels of bioenergy feedstock under range of silvicultural intensities
  – Variation in biomass distribution by silvicultural regime
  – Variation in biomass and nutrient removals by regime and logging systems
Biomass Sampling

\[ \text{Biomass} = \beta_1 \text{ DBH} \uparrow \beta_2 \]

Not consistent across differing management regimes.

Wide spacing

Same diameter but very different stem and crown biomass of individual trees: Have to account for diameter AND height.

Close spacing
Biomass Sampling

Bivariate range in diameter and height!!
Biomass Sampling

• Sampled stands and trees
  – Westside Douglas-fir stands, Oregon and Washington
  – Total of 200 trees from 23 sites
  – Age ranged from 12-90 years
  – Included planted and natural stands
  – Included stands subject to intensive competing vegetation control, stand density manipulations, and nitrogen fertilization
Biomass Sampling

• **Biomass components**
  – Foliage (1, 2, 3+ yr old)
  – Live branchwood (wood + bark)
  – Dead branchwood (wood + bark)
  – Stem bark
  – Sapwood
  – Heartwood
### Biomass equations

<table>
<thead>
<tr>
<th>Biomass component</th>
<th>Predictors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foliage</td>
<td>Live crown length and width</td>
</tr>
<tr>
<td>Live branches</td>
<td>Live crown width and % foliage</td>
</tr>
<tr>
<td>Dead branches</td>
<td>Diameter, height, clear bole length</td>
</tr>
<tr>
<td>Bark</td>
<td>Diameter, height, live crown ratio</td>
</tr>
<tr>
<td>Heartwood + sapwood</td>
<td>Diameter, height, live crown ratio</td>
</tr>
<tr>
<td>% sapwood</td>
<td>Diameter, height, live crown ratio</td>
</tr>
<tr>
<td>Sapwood</td>
<td>% sapwood, sapwood + heartwood</td>
</tr>
<tr>
<td>Heartwood</td>
<td>% sapwood, sapwood + heartwood</td>
</tr>
</tbody>
</table>
Tissues sampled for aboveground nutrient content

- **Foliage** (1, 2, 3 yr old, from mid-crown primary branch of each 10\textsuperscript{th} and 90\textsuperscript{th} percentile tree)
- **Live branch** (largest mid-crown branch of each tree)
- **Heartwood, Sapwood, Bark** (from mid-bole disk of each tree)
- **Dead branch** (1 small, 1 large branch from each 90\textsuperscript{th} percentile tree)
Soil sampling
(Paul Footen/Rob Harrison, UW)

- Sampled at four SMC Type I installations
- Sampled to a depth of 1 m
  5-6 horizons per site, with:
  - pH, CEC
  - Bulk density
  - Macronutrient content (N, P, K, Ca, Mg)
Soil nutrient capital
(e.g., N pool ranged from 10 to 22 Mg/ha)
Macro-nutrient concentrations in biomass

- Stems:
  - Heartwood
  - Sapwood
  - Bark

- Roots:
  - Heart
  - Sap
  - Brk
  - Fine

- Foliage:
  - Year 1
  - Year 2
  - Year 3

- Live Branches:
  - W/o bark
  - With bark

- Dead Branches

Nutrients:
- Nitrogen (%)
- Phosphorus (mg/Kg)
- Potassium (mg/Kg)
- Calcium (mg/Kg)
- Magnesium (mg/Kg)
Total aboveground nutrients

Douglas-fir tree, 38 yrs old
dbh=45.6, height =33.5, crown length = 19.9
Balance between harvest removals, replenishment rates, and initial pools

• Project tree lists to harvest age (40 years) with growth model
• Estimate:
  – Standing biomass
  – Biomass removed for utilization
  – Nutrient losses
• (Compare losses to initial nutrient pools -> Evans stability ratio)
• (Alternatively) Simulate fluxes:
  – Organic decomposition (=retained biomass)
  – Parent material weathering rate
  – Atmospheric deposition
  – Leaching loss
  – Biological fixation rate (nitrogen)
• Simulate uptake by forest re-growth, potential limitations to production
Total aboveground nutrients @ 40 yrs
SMC Type I – Roaring River (SI 46.5m @ 50 yrs)
Nitrogen cycle

- Atmospheric deposition
- Biological fixation
- Forest vegetation
- Forest litterfall
- Soil organic matter
- Mineral soil
- Leaching loss

Removal in harvested timber & biofuel feedstock

Mineralization
Determination of harvest removals

- Tree list projected to 40-yr rotation with SMC-ORGANON
- Apply tree-level biomass equations to tree list
- Nutrient content = biomass \cdot \text{average nutrient concentration}
- Partial harvest of top of stem and percentage of crown
Harvest intensity, residual material

- Whole tree—nothing left in woods
- Bole only—entire crown left in woods
- Merchantable—everything above 5” diameter + vertical half of crown below 5” diameter left in woods
- NARA—whole tree; 67.2% of crown residuals are recoverable (average from Kevin Boston’s work)
Nutrient retention, removing bole only
Nutrient retention, removing bole + crown material
Nutrient retention, removing 67% of crown material during stem extraction
Total aboveground nutrients @ 40 yrs
SMC Type I – Roaring River (SI 46.5m @ 50 yrs)
Nutrient flux

- **Flux based on base cation model:**
  - **Additions**
    - Weathering + atmospheric deposition
    - (Biological fixation from atmosphere for N)
  - **Subtractions**
    - Leaching + harvest removals
Published nutrient fluxes in DF forests

- Published values are typically focused on only a few locations
- Values for specific locations are based on balancing inputs and outputs
- Subset of values included for this analysis were those from studies which included balanced data
Average of published nutrient fluxes in Douglas-fir forests

<table>
<thead>
<tr>
<th>Flux type</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
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</thead>
<tbody>
<tr>
<td>Deposition</td>
<td>1.43</td>
<td>0.27</td>
<td>0.38</td>
<td>0.73</td>
<td>0.89</td>
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<tr>
<td>Weathering</td>
<td></td>
<td>0.20</td>
<td>9.95</td>
<td>68.70</td>
<td>7.20</td>
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<tr>
<td>Leaching</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cascades</td>
<td>1.05</td>
<td>0.41</td>
<td>5.30</td>
<td>63.75</td>
<td>9.00</td>
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<tr>
<td>Coastal</td>
<td>5.94</td>
<td>0.02</td>
<td>6.43</td>
<td>8.24</td>
<td>7.83</td>
</tr>
</tbody>
</table>
Evans Stability Ratio

- Ratio of removed nutrients to initial site nutrient capital (expressed as %)
- Used as index of sustainability
- <10%: little risk to productivity
- >10% and <30%: moderate risk to productivity
- >30%: significant risk to productivity
Evans Stability Ratio

Roaring River

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WT</strong></td>
<td>-3</td>
<td>-0.53</td>
<td>-16.1</td>
<td>-6.33</td>
<td>-0.4</td>
</tr>
<tr>
<td><strong>BO</strong></td>
<td>-1.88</td>
<td>-0.4</td>
<td>-12.03</td>
<td>-5.05</td>
<td>-0.3</td>
</tr>
<tr>
<td><strong>Merch</strong></td>
<td>-2.05</td>
<td>-0.41</td>
<td>-12.36</td>
<td>-5.22</td>
<td>-0.31</td>
</tr>
<tr>
<td><strong>NARA</strong></td>
<td>-2.63</td>
<td>-0.49</td>
<td>-14.76</td>
<td>-5.91</td>
<td>-0.37</td>
</tr>
</tbody>
</table>

Harvest removals as % of initial soil and forest floor pool

**Medium risk**

10-30%

**Low risk**

<10%

NARA
### 40 year % change in nutrient capital

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>-2.89</td>
<td>-0.51</td>
<td>0.22</td>
<td>-2.38</td>
<td>-0.67</td>
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<tr>
<td>BO</td>
<td>-0.66</td>
<td>-0.25</td>
<td>8.36</td>
<td>0.17</td>
<td>-0.45</td>
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<tr>
<td>Merch</td>
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<td>-0.27</td>
<td>7.70</td>
<td>-0.17</td>
<td>-0.48</td>
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<tr>
<td>NARA</td>
<td>-2.16</td>
<td>-0.42</td>
<td>2.89</td>
<td>-1.54</td>
<td>-0.60</td>
</tr>
</tbody>
</table>

- Net flux of **-2.89%** for N under WT harvest implies depletion after **34 40-yr rotations** (if fluxes accurate and conditions remain stable)
- **Potassium increases** (=>high weathering rate)
- Relatively low risk to long term site productivity, regardless of harvest intensity
### 40 year % change in nutrient capital

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<thead>
<tr>
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<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>WT</td>
<td>-2.56</td>
<td>-0.36</td>
<td>-0.51</td>
<td>-14.03</td>
<td>-0.40</td>
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<tr>
<td>BO</td>
<td>-0.55</td>
<td>0.08</td>
<td>2.29</td>
<td>-9.29</td>
<td>0.01</td>
</tr>
<tr>
<td>Merch</td>
<td>-1.17</td>
<td>-0.04</td>
<td>1.48</td>
<td>-10.85</td>
<td>-0.11</td>
</tr>
<tr>
<td>NARA</td>
<td>-1.90</td>
<td>-0.21</td>
<td>0.41</td>
<td>-12.48</td>
<td>-0.26</td>
</tr>
</tbody>
</table>

- Calcium source in coastal soils mostly atmospheric (assumption of no weathering)
- % removed highly dependent on leaching
- Calcium flux of **-14.03%** under WT implies **only 7 40-yr rotations** before potential calcium limitations, although unclear whether the decline would be gradual or sudden
Thanks for your attention!