The mixture effect in Scots pine and Norway spruce stands on wood production

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Outline of the talk

1. Publications, experimental sites and stand characteristics
2. Was the pine-spruce mixture more productive than the adjacent monocultures?
3. How much does the mixture effect differ over time?
4. Are the studies comparable and complementary?
5. Conclusions
Material

- 6 published studies with mixed and pure stands of at least one monoculture on the same site
- 3 unpublished studies

<table>
<thead>
<tr>
<th></th>
<th>Pine</th>
<th>Spruce</th>
<th>Mixture (PS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Unpublished</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>
## Material

<table>
<thead>
<tr>
<th></th>
<th>1 SE N</th>
<th>2 SE C</th>
<th>3 SE S</th>
<th>4a UK 1</th>
<th>4b UK 2</th>
<th>5 POL</th>
<th>UN SE 4</th>
<th>Sata FIN</th>
<th>Neu GER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Observed stand age (yrs)</strong></td>
<td>0-31</td>
<td>5-43</td>
<td>16-44</td>
<td>0-28</td>
<td>0-20</td>
<td>50-124(^1)</td>
<td>ca. 30-65?</td>
<td>0-10</td>
<td>46-68</td>
</tr>
<tr>
<td><strong>N of sites</strong></td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>N of plots</strong></td>
<td>360 P 120 S 120 PS 120</td>
<td>360 P 3 S 1 PS 4</td>
<td>8 P 3 S 3 PS 3</td>
<td>9 P 3 S 3 PS 3</td>
<td>9 P 3 S 3 PS 3</td>
<td>12 P 6 PS 6</td>
<td>12 P 4 S 4 PS 4</td>
<td>18 P 6 S 6 PS 6</td>
<td>3 P 1 S 1 PS 1</td>
</tr>
<tr>
<td><strong>Plot size</strong></td>
<td>3 m rad</td>
<td>3 m rad</td>
<td>0.1 ha</td>
<td>0.1 ha</td>
<td>0.1 ha</td>
<td>0.25 ha</td>
<td>0.1 ha</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Latitude</strong></td>
<td>67</td>
<td>60</td>
<td>58</td>
<td>54</td>
<td>54</td>
<td>53</td>
<td>64</td>
<td>61</td>
<td>44</td>
</tr>
<tr>
<td><strong>Initial spruce% in mixture</strong></td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>45-49</td>
<td>50</td>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td><strong>Management</strong></td>
<td>excl.</td>
<td>excl.</td>
<td>equal densities</td>
<td>excl.</td>
<td>excl.</td>
<td>minimized</td>
<td>excl.</td>
<td>excl.</td>
<td>minimized</td>
</tr>
</tbody>
</table>

\(^1\) single stand ages from 35-50 to 124-132 years, \(^2\) extrapolated from yield tables, \(^3\) Mean height used to determine SI according to the yield table.
Method

\[
\frac{\text{PAI } ps_{/ha}}{\text{PAI } p_{/ha}} \times \frac{\text{(Periodic Increment } ps_{/ha})}{\text{(Periodic Increment } p + s_{/ha})} = \frac{\text{PAI } ps_{/ha}}{\text{PAI } s_{/ha}}
\]
# Growth and growth variation

<table>
<thead>
<tr>
<th>Unit, Growth variable</th>
<th>1 SE N</th>
<th>2 SE C</th>
<th>3 SE S</th>
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<th>UN SE 4</th>
<th>Sata</th>
<th>Neu GER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total yield</td>
<td>m³/ha</td>
<td>m³/ha</td>
<td>m³/ha</td>
<td>m²/ha</td>
<td>m²/ha</td>
<td>m³/ha</td>
<td>m³/ha</td>
<td>m, Ø tree height</td>
<td>m³/ha, PI</td>
</tr>
<tr>
<td>Stand age</td>
<td>0-31</td>
<td>0-43</td>
<td>16-57</td>
<td>0-28</td>
<td>0-20</td>
<td>50-124</td>
<td>?</td>
<td>0-10</td>
<td>46-68</td>
</tr>
<tr>
<td>Yield p (pure pine)</td>
<td>34.1 ± 1.17</td>
<td>304 ± 27.75</td>
<td>147 ± 18.68</td>
<td>32.5 ± 7.9</td>
<td>16.2 ± 0.1</td>
<td>4.03 ± 0.76</td>
<td>153 ± 53</td>
<td>442 ± 111</td>
<td>439</td>
</tr>
<tr>
<td>Yield s (spruce)</td>
<td>8.1 ± 0.54</td>
<td>98 ± 8.95</td>
<td>188</td>
<td>28.8 ± 6.3</td>
<td>16.2 ± 5.0</td>
<td>-</td>
<td>19 ± 8</td>
<td>375 ± 57</td>
<td>596</td>
</tr>
<tr>
<td>Yield ps (mixture)</td>
<td>28.6 ± 1.23</td>
<td>244 ± 22.27</td>
<td>183 ± 20.33</td>
<td>37.5 ± 3.9</td>
<td>22.1 ± 1.3</td>
<td>7.55 ± 0.79</td>
<td>96 ± 40</td>
<td>453/335</td>
<td>504</td>
</tr>
<tr>
<td>( \frac{PAI \text{ ps/ha}}{PAI \text{ p + PAI \text{ s/ha}}} )</td>
<td>1.36</td>
<td>1.21</td>
<td>1.16</td>
<td>1.22</td>
<td>1.36</td>
<td>1.36</td>
<td>(1.41²)</td>
<td>1.12</td>
<td>-</td>
</tr>
<tr>
<td>( \frac{PAI \text{ ps/ha}}{PAI \text{ p/ha}} )</td>
<td>0.84</td>
<td>0.80</td>
<td>1.24</td>
<td>1.15</td>
<td>1.36</td>
<td>1.87</td>
<td>0.63</td>
<td>-</td>
<td>1.15</td>
</tr>
<tr>
<td>( \frac{PAI \text{ ps/ha}}{PAI \text{ s/ha}} )</td>
<td>3.53</td>
<td>2.49</td>
<td>0.97</td>
<td>1.30</td>
<td>1.36</td>
<td>5.05</td>
<td>-</td>
<td>0.85</td>
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Spruce failed in mix!

² extrapolated from yield tables
Yield during the whole observation of the experiments
## Growth, growth variation and mixture effect

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<td>1.21</td>
<td>1.16</td>
<td>1.22</td>
<td>1.36</td>
<td>(1.41²)</td>
<td>1.12</td>
<td>-</td>
<td>0.97</td>
</tr>
<tr>
<td>1th period of observation</td>
<td>-</td>
<td>1.41</td>
<td>1.09</td>
<td>-</td>
<td>1.33</td>
<td>1.00</td>
<td>?</td>
<td>-</td>
<td>0.95</td>
</tr>
<tr>
<td>Last period of observation</td>
<td>-</td>
<td>1.12</td>
<td>1.18</td>
<td>-</td>
<td>1.39</td>
<td>1.43</td>
<td>?</td>
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Spruce failed in mix!
The mixture effect size over time

- Limited to sites with both monocultures and data accessible -
The effect size of admixing spruce to pine
The effect size of admixing pine to spruce

\[
\frac{\text{PAI ps/ha}}{\text{PAI s/ha}}
\]
How does stand age influence mixture and admixing effects?

General mix effect depending on initial age

![Graph showing general mix effect](image1)

Admixing spruce depending on initial age

![Graph showing admixing spruce](image2)

Admixing pine depending on initial age

![Graph showing admixing pine](image3)
How does latitude or site index influence mixture effects?

**General mix effect depending on latitude**

\[ y = 0.0246x - 0.3203 \]
\[ R^2 = 0.23 \]

- General mix effect
- Linear (General mix effect)

**General mix effect depending in SI**

\[ y = -0.0236x + 1.8567 \]
\[ R^2 = 0.43 \]

- General mix effect
- Linear (General mix effect)

**Admixing spruce depending on latitude**

- Admixing spruce
- Linear (Admixing spruce)

**Admixing pine depending on latitude**

- Admixing pine
Mean size ratio of tree species and mixture proportion: influencing mixture effects?

**General mixture effect depending on spruce%**

- **General mix effect depending on mean size ratio P/S**

**Admixing spruce depending on spruce%**

- **Admixing spruce depending on mean size ratio P/S**

Mathematical equation:

\[ y = 0.008x + 0.7083 \]

\[ R^2 = 0.50 \]
The mixture effect size over time

- Limited to sites with both monocultures and data accessible -
The mixture effect size over time

Limited to sites with both monocultures and data accessible

Complementing missing observations in pure spruce by yield tables
The mixture effect size over time

\[
\frac{\text{PAI}_{ps}/\text{ha}}{\text{PAI}_{p} + \text{PAI}_{s}/\text{ha}}
\]

- Limited to sites with both monocultures and data accessible
- Complementing missing observations in pure spruce by yield tables +20%
Conclusions from the experiments

• **General mixture effect of +19%**, ranging from -3 to +36% (-6% compared to the most productive monoculture)

• **Decreasing mixture effect over time** (at least in stands younger than 70 years)

• **Effect of admixing spruce increases over time**, but negative during first decades or in highest latitudes

• **Positive effect of admixing pine decreases over time**

• Stand age and site index seem to have an important impact on the mixture effect, while mean tree size ratio and spruce proportion may not have such a strong impact
Limitations

• Only 16 sites, not representative for 8 million ha (5 sites outside the natural distribution of one of the species)
• Pure spruce forest not included as treatment on 5 sites and failed in 1 case
• Limited time windows
• Various ways/methods to calculate mixture effects
• Management mostly excluded in the exp.
How to go further?

• Mix effect = f(stand age, SI, latitude, density, tree size ratio, mix%,...?)
• Using yield tables and growth models
  a) to complement the picture, and
  b) to test the models
    – MOTTI, ProdMod, Heureka, Bwin
• Mixture effect related to the most productive monoculture, and time until growth culmination
• Hundreds of mixed forest plots with documented stand tree growth
  (á la Mielikäinen 1980 and Agestam 1985)
• Hybrid models?
Thank you!

Special thanks to all the people involved in the experiments (from Schwappach to the current field measurement teams). Thanks also to the Southern Swedish Forest Research Centre and the Nordic Forest Research council for the financial support, and to Urban Nilsson for data provision about the mixed pine-spruce experiment in northern Sweden.