Effects of harvested tree size and density of undergrowth on the operational efficiency of a bundle-harvester system in early fuel wood thinnings

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Demand for biomasses for biorefining will rise....

-Use of bundle-harvesting systems for young dense thinnings could significantly reduce supply costs for small diameter trees (Bergström & Di Fulvio 2014, SJFR)....

-A 3rd version of the Fixteri bundle-harvester has shown increases in efficiency of 90-160%. Bundles increases forwarders’ and trucks’ payloads by ca 50% (Björheden & Nuutinen 2014, Skogforsk report...).

-System’s productivity has not been extensively studied in stands < 30 dm³, in which there may be significant proportions of disturbing under-growth trees (cf. Kärhä 2006 For. Stud.).
Objectives

• The objective of the study presented here was to evaluate effects of:
  
  a) harvested tree size
  
  b) and density of undergrowth

  on the operational efficiency of the third prototype of the bundle-harvester in early fuel wood thinnings.
Study design

• Scots pine dominated stands (by volume)
• 26 harvesting units where inventoried
• Time studies
• Measures of:
  – bundle mass
  – MC
  – Thinning quality etc...
• Analysis of time consumption, productivity....
## Stand characteristics

<table>
<thead>
<tr>
<th>Stats</th>
<th>DBH basal (cm)</th>
<th>Stem volume (dm³)</th>
<th>Density (trees/ha)</th>
<th>Height (m)</th>
<th>Tot volume (m³/ha)</th>
<th>Density trees &lt;2.5 cm (n/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>8.0</td>
<td>26.5</td>
<td>5406</td>
<td>8.2</td>
<td>189.2</td>
<td>4523</td>
</tr>
<tr>
<td>Min</td>
<td>6.3</td>
<td>15.0</td>
<td>2765</td>
<td>7.0</td>
<td>124.0</td>
<td>134</td>
</tr>
<tr>
<td>Max</td>
<td>9.9</td>
<td>43.0</td>
<td>9302</td>
<td>9.7</td>
<td>302.0</td>
<td>11951</td>
</tr>
<tr>
<td>Median</td>
<td>8.0</td>
<td>24.5</td>
<td>5200</td>
<td>8.1</td>
<td>173.5</td>
<td>3648</td>
</tr>
<tr>
<td>SD</td>
<td>1.0</td>
<td>8.1</td>
<td>1583</td>
<td>0.7</td>
<td>48.7</td>
<td>3509</td>
</tr>
</tbody>
</table>
The bundle-harvester system

- 8-wheeled Logman 811FC harwarder (Logman, Oy)
- Logfit FT100 crane (Logfit AB), rotating cabin with endless turning.
- Nisula 280E+ (Nisula Forest Oy) accumulating felling, cutting diam. 28 cm.
- Fixteri FX15a bundleing unit (mass ca. 6,500 kg, width 240 cm, length 410 cm, height 280 cm; www.fixteri.fi).
Machine work sequence

- **Moving**
  - *Crane out*
  - **Fell A, B**
  - **Crane in**
  - **Feed (feeding the bunch of whole-trees onto the feeding table)**
  - **Bundling (Feed rollers pulling the whole trees into the feeding chamber)**
  - **Bundling (the whole trees were cut in feeding chamber)**
  - **Bundling (lifting the cut trees into the central chamber)**
  - **Bundling (compressing and wrapping the cut trees in the compaction chamber)**
  - **Dropping and weighing a bundle**

Next tree at the same working location?

**CUTTING PROCESS**

**BUNDLING PROCESS**

**MISCELLANEOUS TIMES**

Arrangement of felled trees
Arrangement of produced bundles
Delays (interruption)
A bundle
2.6m length
60-70 cm diam.
0.45-0.5 m³
**Results**: Work-efficiency >> no differences between treatments!

<table>
<thead>
<tr>
<th>Work element</th>
<th>Mean (sec/tree)</th>
<th>SD</th>
<th>(%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Move</td>
<td>0.8</td>
<td>0.2</td>
<td>7.4</td>
<td>0.661</td>
</tr>
<tr>
<td>Fell</td>
<td>5.8</td>
<td>0.5</td>
<td>51.6</td>
<td>0.229</td>
</tr>
<tr>
<td>Crut</td>
<td>1.5</td>
<td>0.4</td>
<td>13.2</td>
<td>0.902</td>
</tr>
<tr>
<td>Crin</td>
<td>2.1</td>
<td>0.6</td>
<td>18.6</td>
<td>0.792</td>
</tr>
<tr>
<td>Artr</td>
<td>0.1</td>
<td>0.1</td>
<td>1.1</td>
<td>0.901</td>
</tr>
<tr>
<td>Arbu</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.240</td>
</tr>
<tr>
<td>Bundle</td>
<td>0.5</td>
<td>0.3</td>
<td>4.5</td>
<td>0.848</td>
</tr>
<tr>
<td>Drop</td>
<td>0.3</td>
<td>0.1</td>
<td>2.9</td>
<td>0.660</td>
</tr>
<tr>
<td>Other</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>0.658</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11.2</strong></td>
<td><strong>2.0</strong></td>
<td><strong>100</strong></td>
<td><strong>0.864</strong></td>
</tr>
</tbody>
</table>
Correlation between cutting and bundling work

![Graph showing the correlation between time consumption per crane cycle (sec) and time consumption per bundle (min).]
Productivity, mass

![Graph showing the relationship between stem volume (dm³) and productivity (ODt/PMH) for two treatments: NO PCT and PCT. The graph includes a trend line and data points for each treatment.](image-url)
Productivity, bundles

![Graph showing the relationship between stem volume (dm³) and productivity (bundles/PMH) for two treatment groups: NO PCT and PCT. The graph indicates a positive correlation between stem volume and productivity.]
During 98.5 PM$_{15}$H:
- 15.87 MWh of diesel fuel were consumed
- 1392.36 MWh of biofuel were produced
>>> average energy efficiency of 172 MJ/OD t (187 MJ/OD t in PM$_{15}$ time) and an EROEI of 80.6 (87.7 in PM$_{15}$ time).

(fuel consumption averaged 15.1 l/PM$_0$H (16.4 l/PM$_{15}$H))

Average a bundle mass: 454 kg, fresh = 0.96 MWh

Additional test:
Tree sections lost 37 kg (SD 29) mass during the bundling process = 7.1% of mass!
By visual inspection this mass consisted mainly of fine branches and needles.
Conclusions

- Unexpectedly, the density of undergrowth trees did not significantly affect the efficiency of the cutting work, as found in previous studies (e.g. Kärhä 2006, Jonsson 2015 MSc at SLU).

- Accordingly, Jonsson (2015) found that defoliated undergrowth reduces visibility much less than fully leafed trees.
  - *The undergrowth did not affect the quality of the thinning work either, which is consistent with the hypothesis that the undergrowth did not significantly impair visibility for the operator*....

- Few of the harvested units in our study had dense spruce undergrowth,
  - *which may be significant as spruce has greater branchiness than pine and birch (Kärhä (2006), and thus may have stronger effects*....
Conclusions

The study provides information about the system’s performance that complements earlier findings, especially when handling relatively small trees!
...additional explanation:

- the cutting work in the present study was performed with an accumulating felling head equipped with shearing knives that is less sensitive to disturbing undergrowth during cutting than the accumulating harvester heads used in the cited studies.
-Simple, robust och unsensitive for undergrowth, stones...!
(but rel. slow!)

Figure 6. Felling and harvester heads used in the study. From the left the Bracke C16-a disc saw head, the Log Max 4000B harvester head and the Naarva-Grip 1500-40E guillotine head.
Photo: Helmer Belbo

The bundling unit’s maximum efficiency was not reached during the trial, but estimates indicate that it could be significantly (perhaps up to 100%) higher.

- However, to reach such efficiency the system would have to be equipped with a felling and bunching head that can cut and accumulate trees during continuous boom movements.
Boom-corridor thinning methods + New cutting technology + Integrated bundling

Next step(s)....
Prototypes!
- MAMA-head
- "Flowcut"!
[Forest Engineers Raul Fernandez Lacruz and Mikael Öhman are acknowledged for helping out with the field work.]

• Thanks, Dan, Fulvio and Yrjö!

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