Transforming even-aged coniferous stands to uneven-aged stands: an opportunity to increase tree species diversity?

Gauthier Ligot¹, Philippe Balandier², Sophie Schmitz³, Hugues Claessens¹

¹ ULiège, Gembloux Agro-Bio Tech, Belgium
² Forest Ecology and Ecophysiology, Irstea, Nogent-sur-Vernisson, France
³ CRA-W, Gembloux, Belgique
Even-aged to uneven-aged

• Coniferous plantations (monoculture), still cover large areas in Europe
  – 50% of forest areas in Belgium
  – Traditionnally, these stands are managed with clear-cuts and plantations

• Silviculture avoiding clear-cutting is more and more encouraged or even imposed by regulation
  – Pro-Silva silviculture must be applied in state-owned forest in Belgium
  – Clear-cuts are forbidden in peri-urban forests around Paris, France
  – ...

• But very few guides for practionners...
  – How long does it take to reach an equilibrium state and to harvest the planted trees?
  – What is the forest productivity during the transformation period?
  – What will be the composition (and resilience) of future uneven-aged stands?
Understory light is assumed to be a key factor of natural regeneration

- Assumed to be a limiting factor under continuous cover forestry
Understory light is assumed to be a key factor of natural regeneration

- Assumed to be a limiting factor under continuous cover forestry
- Understory light levels can be controlled by partial cuttings
Understory light is assumed to be a key factor of natural regeneration

- A limiting factor under continuous cover forestry
- Understory light levels can be controlled by partial cuttings
- Drive inter-specific competition

adapted from Smith et Huston (1989) *Vegetatio* 83:49-69
Understory light is assumed to be a key factor of natural regeneration

- A limiting factor under continuous cover forestry
- Understory light levels can be controlled by partial cuttings
- Drive inter-specific competition
- The apical dominance ratio has been suggested to be a good indicator of understory light conditions for some species

\[
ADR = \frac{\text{terminal shoot length}}{\text{Longest lateral shoot length}}
\]
Research questions

• Can we expect that tree species diversity will increase in stands managed without clear-cut? What are the light conditions that best promote species diversity? Can we control it?

• Is the Apical Dominance Ratio (ADR) a good indicator of understory light for that purpose?
9 coniferous stands in Belgium at 400-600 m a.s.l.

<table>
<thead>
<tr>
<th>Study area</th>
<th>Young 35 year old</th>
<th>Mature 60 year old</th>
<th>Old 80-150 year old</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spruce</strong></td>
<td><img src="image" alt="Spruce trees" /></td>
<td><img src="image" alt="Spruce trees" /></td>
<td><img src="image" alt="Spruce trees" /></td>
</tr>
<tr>
<td><em>Picea abies</em> (L.) Karst</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Douglas fir</strong></td>
<td><img src="image" alt="Douglas fir trees" /></td>
<td><img src="image" alt="Douglas fir trees" /></td>
<td><img src="image" alt="Douglas fir trees" /></td>
</tr>
<tr>
<td><em>Pseudotsugae menziesii</em> (Mirb.) Franco</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mixed</strong></td>
<td><img src="image" alt="Mixed trees" /></td>
<td><img src="image" alt="Mixed trees" /></td>
<td><img src="image" alt="Mixed trees" /></td>
</tr>
<tr>
<td><em>Picea abies</em> (L.) Karst</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudotsugae menziesii</em> (Mirb.) Franco</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larix sp.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Abies alba</em> Mill.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsuga heterophylla</em> (Raf.) sarg.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Measures

- 1 ha plots in each site
- 12 circular subplots of 3-m radius
Measures

- For the 3 tallest saplings of each species, we measured:
  - Sapling height
  - Terminal shoots
  - Longest lateral shoots
  - Defoliation rate
    - Visual estimate of the percentage of remaining needles on two secondary branches of 3 year old
Measures

- For the 3 tallest saplings of each species, we measured
  - Sapling height
  - Terminal shoots
  - Longest lateral shoots
  - Defoliation rate
    - Visual estimate of the percentage of remaining needles on two secondary branches of 3 year old
  - Competition index
    - Dawkins classification
In spring 2018, 107 hemispherical photographs to measure to percentage of above canopy light (PACL), taken above the regeneration of each subplot (with a telescopic pole and an auto-stabilized device)
Validation of photo thresholding measuring understory light with light sensors during two days in three study sites
Simulations with **SamsaraLightLoader** (Capsis4) to estimate the understory light before 2018 to take into account tree mortality and thinnings.
Summary statistics

- $n = 1354$ measures of terminal shoots of 565 saplings
  - 247 spruces
  - 141 douglas firs
  - 56 larches
  - 58 silver firs
  - 54 hemlocks
- Height up to 445 cm
- PACL varying from 1% to 45%
Modelling terminal shoot length

Non-linear mixed model fitted with the restricted maximum of likelihood

\[
\text{terminal shoot length}_{i,j,k,l} = (a + \alpha_i) \text{height}^b_{i,j,k,l} \text{PACL}^c_{i,j,k} + \varepsilon_{i,j,k,l}
\]

with \(a, b, c\) the fixed parameters
\(\alpha\) a random plot effect: \(\alpha \sim N(0, \sigma_\alpha)\)
\(\varepsilon\) the random residual error: \(\varepsilon \sim N(0, \sigma_\varepsilon)\)
Modelling terminal shoot length

- Terminal shoot logically increased with height and PACL

- Western hemlock, a very shade tolerant species, had terminal shoot about three times that of the other species in all observed light conditions (no saplings of height ≥ 200 cm observed)
Modeling terminal shoot length

- Not considering Western Hemlock:
  - In low light conditions, all species grow at relatively similar height growth rates
  - In high light conditions, some species can grow faster than others. They are by order of decreasing height increment:
    1. Larch (shade intolerant)
    2. Spruce (shade tolerant)
    3. Silver fir (very shade tolerant)
    4. Douglas fir (less shade tolerant)
What’s wrong with the Douglas fir?

- We expected larger height increment and stronger response to light
Increased sensitivity to different pest and pathogens in the recent years (abundance of necroses and important defoliation):

- *Phaeocryptopus gaeumannii* (Swiss needle cast)
  - Identified in 5/5 sites
- *Sirococcus conigenus*
  - Identified in 4/5 sites
- *Sydowia sp.*
  - Identified in 2/5 sites
- *Botrytis sp.*
  - Identified in 1/5 sites
- *Contarinia pseudotsugae*
  - Identified in 5/5 sites, 20-40% of needles had galls caused by this insect
Defoliation rate and Douglas Fir growth

- In average, Douglas fir saplings had a defoliation rate of 50% while silver fir and spruce had a defoliation rate of about 20%.

- We found a weak but significant correlation between the residuals of the height increment model for Douglas fir and the defoliation rate.
ADR: a good indicator of understory light?

- For all species but Western Hemlock, the relationships between ADR and PACL are significant but weak: $R^2 < 19\%$

- PACL estimate at subplot center may not be accurate enough to estimate the light transmitted to the saplings (sometimes 3m away from the subplot center)

- Other factors likely interact (e.g. pathogens)

- Picking one sapling at random and estimating its ADR, will likely not provide an accurate measure of understory light (within the studied range of light conditions (1-40\%))
Is the conversion from even-aged to uneven-aged an opportunity to increase future stand diversity?

- Hemlock regeneration generally outcompeted other tree species. This thread can likely not be avoided by controlling understory light (within the range of light conditions observed with continuous cover forestry).

- Natural regeneration of Douglas fir in Belgium suffers from different pest and pathogens which likely reduce its competitiveness and future abundance.

- Maintaining closed canopies can be used to reduce the vigor of the most vigorous species and increases the probability of less vigorous species to be recruited.
Perspectives

• Implement these models in a forest dynamics simulator to simulate the conversion of even-aged to uneven-aged structure and provide silvicultural guides

• Continue evaluating regeneration dynamics and in particular sapling and young tree survival

Samsara2 model