CARBON BALANCE OF DIFFERENT SILVICULTURAL SYSTEMS

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![Graph showing basal area over time](graph.png)
Even-aged management

Good-quality, naturally emerged stand is replaced by low-quality plantation
Wood quality of pine is a problem

Plantation forestry & low thinning result in low wood quality (low value of sawn wood, 120 €/m³)

Naturally regenerated stands treated with high thinnings produce good-quality wood (400 €/m³)

Plantation forestry aims at fast early growth -> low wood quality
The aim should be exactly opposite! (max 1-mm annual rings)
Continuous cover management

All management systems that do not use clear-felling & planting

- Uneven-aged forestry (Plenter forests)
- Removal of overstorey in two-layered stands
- Seed tree and shelter wood methods
- Repeated high thinnings
- Use of natural species dynamics
  - Natural hardwood
  - Spruce undergrowth
  - Mixed 2-layer stand
  - Uneven-sized spruce stand
  - High thinnings
  - Natural regeneration for hardwood
Typical Finnish forest
Most Finnish forests are uneven-sized
Uneven-aged management

- Decreasing diameter distribution (reversed J)
- Steady state management
- Constant cutting cycle
  - 15 – 50 v
- Cutting always returns the same diameter distribution
Uneven-aged management

- High thinning
- High thinning
- High thinning
- High thinning
- High thinning
- High thinning
- High thinning

![Graph showing basal area vs. time for uneven-aged management](image-url)
Uneven-aged management is not only for spruce
Uneven-aged pine forest
A few words about carbon balance

- Natural rain forest is not a carbon sink
  - Its carbon balance = 0 (or close to zero)
  - Carbon is sequestrated as long as biomass increases
  - The carbon balance of non-managed tropical forests will be eventually zero
  - In the north, carbon accumulates slowly in forest soil

- Cutting in a tropical rain forest does not always result in negative carbon balance
  - Permanent destruction (for oil palm, grazing) means carbon releases
  - The effect of selective cuttings depends on products and harvest technology
  - Long-life products store carbon
  - Thinning enables biomass growth
  - The total effect may be positive or negative
More words about carbon balance

- The steady-state carbon balance of biological processes is zero
  - Biomass growth (positive factor) and decomposition (negative) are equal

- Management and harvesting lead to negative balance
  - Harvesting and transportation releases
  - Processing releases

- Substitution effects may result in positive balance
  - Biofuels may replace fossil fuels
  - Construction wood decreases the use of cement and steel

- Timber assortments have different balances
  - Biofuel: good because of substitution effects
  - Sawn wood, plywood: good (long-term C store, substitution effects)
  - Pine pulp wood: OK (chemical process, a part used for biofuel)
  - Spruce pulpwood: very bad (high processing releases, no substitution effects)
Calculation of carbon balance

Two variables commonly used

- **Carbon Stock (CS) at certain time point**
  - $\text{CS} = 0.5 \times \text{Biomass}$
  - Does not tell whether the forest is carbon source or sink
  - Change in carbon stock more informative in this respect

- **Carbon Balance (CB) of a certain time period**
  - $\text{CB} = \text{Sequestrated carbon} - \text{Released carbon}$
  - Positive balance: forest is carbon sink
  - Negative balance: forest is carbon source
Calculation of carbon balance

Requires

- Simulation of stand dynamics
- Calculation of biomass
  - Models or expansion factors
  - Stem: volume x basic density
  - Branches & leaves: $BM = f(d, h)$
  - Roots & stump: $BM = f(d, h)$
- Simulation of decomposition of
  - Dead trees
  - Cutting residues
  - Products
Simulation of stand dynamics

Several models and simulators available

Mortality

Growth

Ingrowth
Calculation of carbon balance

- Change of living biomass ($B$, +/-)
- Biomass of harvested trees ($H$, +)
- Biomass of mortality ($M$, +)
- Decomposition of dead material in the forest (cutting residues, dead trees) ($P$, -)
  - Decomposition of initial dead material
  - Decomposition of new dead material
- Decomposition outside the forest (products) ($T$, -)
  - Decomposition of products prepared before the calculation period
  - Decomposition of products prepared during the calculation period
- Harvesting and processing releases ($V$, -)
- Substitution effects ($S$, +)

$$CB_{t1,t2} = \alpha(B_{t2} - B_{t1} + H + M) - \alpha(P + T) - V + S$$

$\alpha = \text{share of C of dry mass, carbon content of biomass (around 0.5)}$
Initialisation of decomposing material

- Simulation needs initialization
  - Initial dead material in the forest (amount and state)
  - Products prepared before the calculation period (amount and state)

- A common procedure:
  - Read (some) initial values from a parameter file
  - Simulate certain type of management for a few rotations (even-aged management) or cutting cycles (uneven-aged)
  - Use the ending amounts of decaying materials as starting values for the next rotation or cutting cycle
Simulation of decomposition

1. \( B_t = B_0 \exp^{-kt} \) \((k = \text{annual decomposition rate})\)
   - \(k\) depends on tree species, size of the tree

2. Empirical models, e.g. Mäkinen et al.
   - Available for stems only

3. Yasso
   - Dead material divided into chemical components
   - They have different decomposition rates \((k)\)
   - Transition between components simulated

The results of this presentation are based on Method 1
Simulation of decomposition

Pine down wood stem, dbh 20 cm

Remaining biomass vs. Time, years

- k (Pukkala)
- Mäkinen
- Yasso K-S
- Yasso E-S
Decomposition of residues

The graph illustrates the decomposition of residues over time. The x-axis represents time in years, ranging from 0 to 100, while the y-axis shows the remaining carbon (C) content from 1 to 0. The graph includes lines for different types of residues:

- Dotted line: Branches
- Dashed line: Needles
- Solid line: Stump+Roots
- Black solid line: All residues

The lines show exponential decay, indicating the decrease in carbon content over time for each residue type.
Decomposition of products

- A felled tree is partitioned into:
  - Sawlog part
  - Pulpwood part
  - Stem energy wood
  - Branch/stump/root biofuel (2/3 of dry mass, if collected)

- The sawlog part further subdivided
  - Long-term (sawn wood, plywood), 50-yr life span (50% of BM left)
  - Mechanical mass
  - Chemical mass
  - Biofuel

- Pulpwood part is subdivided
  - Mechanical mass
  - Chemical mass
  - Biofuel

Different components have different $k$

Decomposition is simulated using

$$B_t = B_0 \exp^{-kt}$$
Decomposition of products

Sawlog
- Sawn wood
- Mass
- Biofuel
- Whole sawlog

Pulp wood
- Mass
- Biofuel
- Whole pulp log
Results for even-aged pine

- Assumed that 3 previous rotations according to current instructions
- Management of the next rotation optimized with different objectives
- Carbon balance during 3 rotations calculated for the optimal schedules
- Substitution effects: 1/2 for biofuel, 1/3 for sawn wood

**Graph:**

- **X-axis:** Time, years
- **Y-axis:** Accumulated carbon, t/ha

**Legend:**

- **Black line:** Current
- **Gray line:** Pulp
- **Dotted line:** Log
- **Dashed line:** Profit
- **Solid line:** Carbon

**Legend boxes:**

**Good schedules**
- Max C balance
- Max NPV (profit)
- Max sawlog yield

**Bad schedules**
- Current management
- Max pulpwood yield
Results for even-aged spruce

How is the Max Carbon balance schedule?
- Very long rotation length
- Very late first thinning
- Only very large trees harvested with almost no pulpwood

Good
- Max C balance

Average
- Max sawlog yield
- Max NPV (profit)

Bad
- Current instructions
- Max pulpwood yield
Effect of biofuel harvesting

Best for carbon balance would be to harvest only sawlogs and biofuel, and no pulpwood.

"No pulpwood" means that pulpwood is used as biofuel.
Without substitution effects forestry is carbon source (in the long run, in a steady state situation)
Afforestation has a much better carbon balance than reforestation for the first rotation since there is no initial decaying material.
Uneven-aged management

The total benefit from timber, carbon and bilberries was maximized except "Current", which follows instructions. Lower substitution rates used than in previous examples (0.4 for biofuel, 0.2 for sawn wood).

Uneven-aged slightly better because only/mostly log-sized trees are harvested (less pulpwood, more sawlog).

This result is without differences in soil respiration.
Two open questions

- Does clearfelling increase carbon releases from soil?
  - Increasing temperature fastens respiration (known fact)
  - Soil is warmer in a clear-felled area than under a tree cover (another fact)
  - Most probably clear-felling increases carbon releases from soil

- What is the influence of using stumps for biofuel?
  - This biofuel may replace fossil fuel -> positive effect
  - Carbon is released much quicker than without biofuel use
  - Full positive effect is reached after several decades
  - Stump harvesting may increase soil respiration
  - The total effect is less positive and reached later than usually expected
Why is the current even-aged management so bad for C balance?

- **Pre-cutting cleaning** reduces biomass, increases decaying material (reduces carbon sequestration, increases releases)
- **Clear-felling** increases carbon releases from soil
- **Site preparation** may increase soil respiration
- **Planting**: slow-growing spruce often planted (spruce is the worst species, spruce pulpwood is the worst assortment)
- **1st tending**: biomass accumulation slows down, decaying material increases
- **2nd tending**: biomass accumulation slows down …
- **1st thinning** is conducted too early, pulpwood is harvested
- **2nd thinning** is conducted as low thinning with a too high removal of pulpwood
Conclusions

- How can we reduce carbon releases from forestry
  - Using longer rotation lengths
  - Postponing the first commercial thinning
  - Using high thinning instead of low thinning
  - Using uneven-aged management
  - Favoring pine and birch instead of spruce
  - Skipping the tending operations of young plantations
  - Using spruce pulpwood as biofuel
Conclusions

- How can forests sequester carbon from atmosphere
  - Biomass is increased
  - Material for long-term products is produced
  - Emission of management, harvesting, transport and processing are reduced
  - Replacing oil by biofuel and steel and concrete by construction wood
  - Afforestation
  - Maintaining a continuous tree cover, avoiding clear-felling and site preparation
One easy question would be welcome