Mitigation of climate change thru boreal forest management

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The Swedish production forest

In Sweden, 55 % or 22,5 million hectares of the land area are covered by managed forests. The main ecosystem from the north is of boreal or semiboreal type. The main species are Norway spruce, Scots pine and Betula ssp, comprising 41, 40, and 13%, respectively, of the growing stock. Forest growing stock is 3 billion m^3, with an annual increase by about 1%. The average annual growth is 4,9 m^3/ha, and the total annual growth is 120 million m^3. Growth has increased by 50% since the 70-s. The annual cut is about 90 million m^3 and the biomass is harvested as timber, pulpwood and fuelwood.

Forest carbon sequestration

During the period 1926-2000, the amount of sequestered carbon dioxide, stored in the trees and in the soil in Swedish conifer forests, have increased from 5,6 to 7,6 billion tons (Ågren et.al 2007) (Figure 1). CO_2 , stored in the soil increased from 3,4 to 3,9 billion tons and CO_2 , stored in the tree biomass increased from 2,2 to 3,7 billion tons. 50% more CO_2 was stored in spruce forests year 2000 (4,6 billion tons), than in pine forests (3 billion tons).

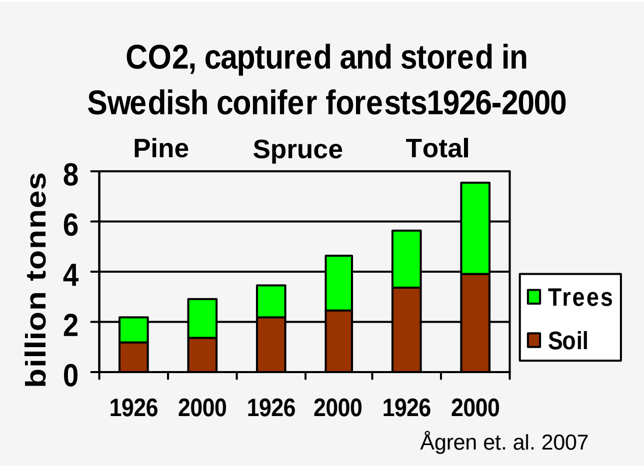


Figure 1. *Carbon dioxide stored in Swedish forest soil and tree biomass 1926 and 2000.*

During the same period, 4,3 billion m^3 stem wood was harvested and utilized as raw material for production of paper, sawn goods and energy. This volume represent a CO_2 sequestration of 3,3 billion tons. Thus, the total CO_2 sequestration between 1926 and 2000, amounts to 5,3 billion tons, or in average 71 million tons/year. This CO_2 capture was about the same as the Swedish CO_2 emissions 2005, being 67 million tons.

Needle area and photosynthesis

Leaf area index (LAI) of a forest is the total leaf area divided by the ground area. Forest CO_2 capture in relation to maximum possible, at the prevailing light intensity, increases with increasing LAI (Figure 2).

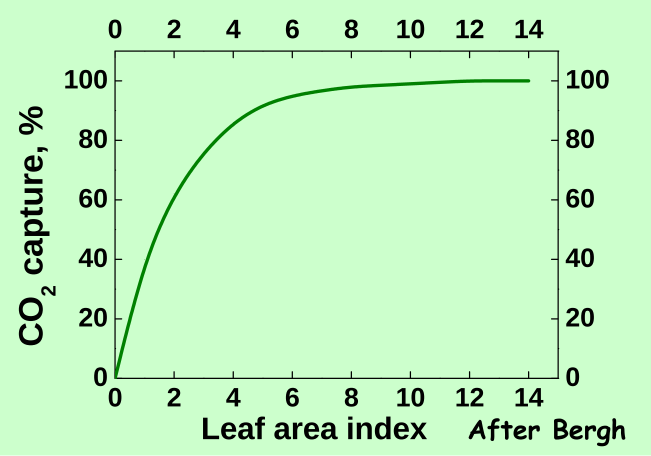


Figure 2. *Leaf area index and relative CO_2 capture in a conifer forest*.

LAI in a dense pine forest may reach up to 6 and in a dens spruce forest to 12. The effect of increasing LAI on CO_2 capture is highest in the LAI range of 0-5, when 90% of the possible CO_2 capture is reached. Increased needle mass will result in increased light absorption, CO_2 capture and tree growth. Therefore, any attempts to increase forest growth should be based on measures that results in increased leaf/needle area.

Forest management for increased tree growth

An increased carbon dioxide sequestration and forest growth might be positive for mitigation of climate change. Needle area may be increased thru forest management, by increasing the number of trees per hectare and/or supply of nitrogen fertilizer, facilitating a higher needle production per tree. Such measures might involve a rapid and complete replanting after final cut as well as keeping stem number and basal area at a higher level than the standard practices throughout the rotation, and in particular during the first 2/3 of the rotation, during which the annual growth reaches the peak value.

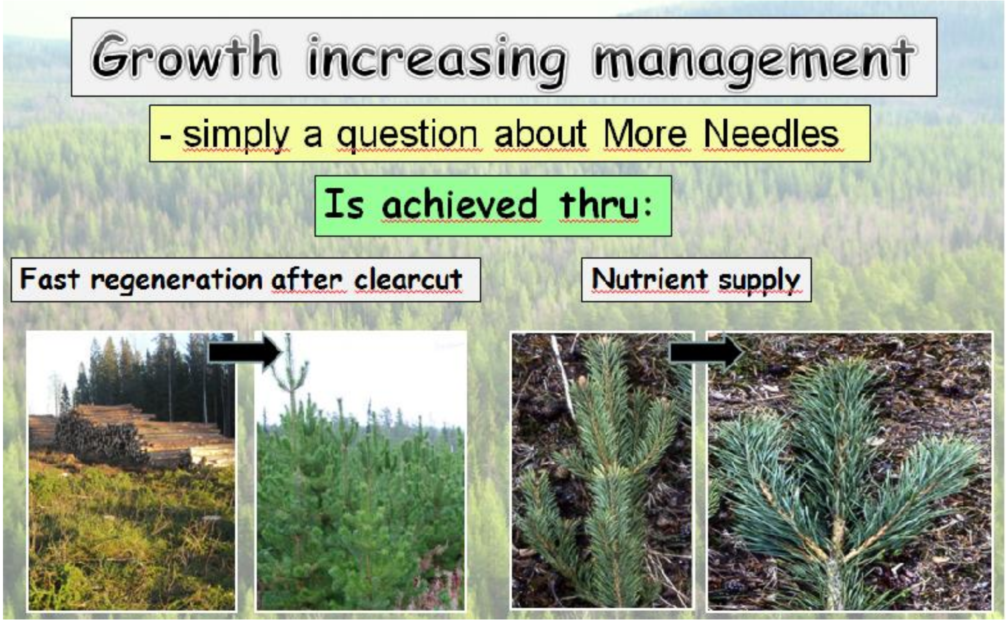


Figure 3. *Fast and dense regeneration and nitrogen nutrient supply result in increased photosynthesizing needle mass.*

Growth increase in field experiments

In two field experiments, carried out in northern Sweden, effects of stem number and nutrient supply on tree growth in young forests, have been investigated for Scots pine and Norway spruce .

One experiment was carried out in 4 pine dominated stands at about 2-3 m height in northern Sweden, with stem numbers between 15000 and 20000/ha (Ahnlund Ulvcrona 2011).
The following 5 treatments were used :

- Precommercial thinning to 3000 stems/ha (PCT) , close to the recommended standard practice in Sweden
- " + fertilization with ammonium nitrate, 100 kg N/ha (PCT+F1)
- No precommercial thinning (C)
- " + fertilization with ammonium nitrate, 100 kg N/ha (C+F1)
- " + annual fertilization with ammonium nitrate, 100 kg N/ha (C+F2)

After 11 years, at 10-12 m height, stem diameters at breast height were measured and biomass production was calculated. Biomass production was 52 tons and 61 tons, respectively for PCT and PCT +F1 (Figure 4) . For the unthinned control, production was 76 tons, and when fertilized, 89 tons and 97 tons, respectively, for F1 and F2. Thus, keeping the forest unthinned, resulted in a higher production of between 24 (46%) and 45 (85%) tons/ha, in comparison with the standard practice thinned treatment PCT. The relative fertilization effect for F1 was 17%, and similar for both C and PCT. Thus, it is possible to achieve considerably increased growth for Scots Pine, if higher stem numbers are applied and nitrogen nutrients are supplied.

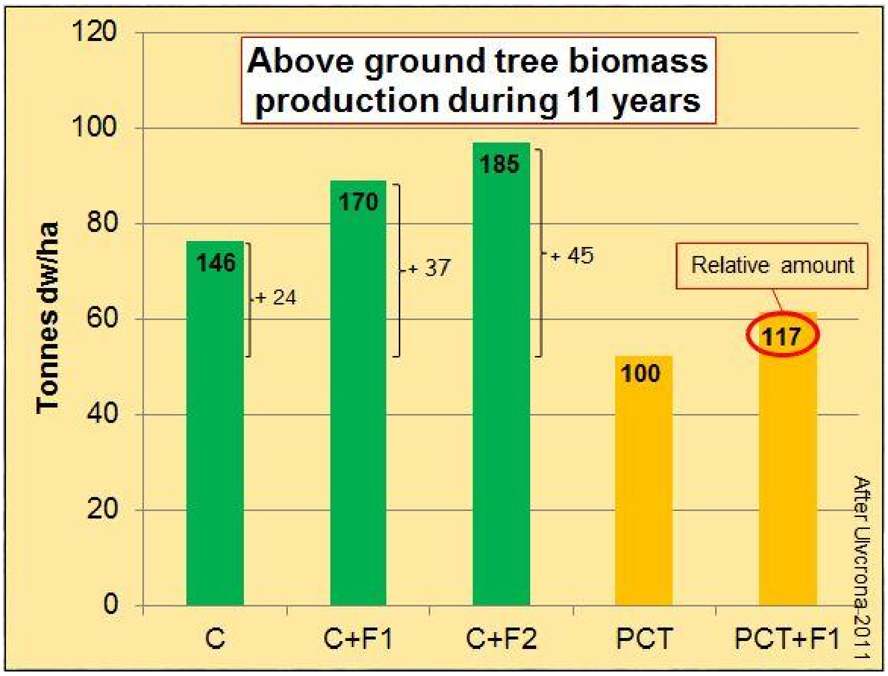


Figure 4. *Biomass growth for young Scots pine during 11 years for unthinned (green bars, 15-20000 stems/ha) and thinned (yellow bars, 3000 stems/ha) treatments, in combination with no fertilization, annual fertilization (F2) and fertilization once at the beginning of the experiment (F1). Fertilizer application rate was 100 kg N/ha.*

The experiment with Norway spruce was established in 1986 under supervision of Professor Sune Linder, SLU. In this experiment, nitrogen based fertilizer was supplied annually. Also other nutrients were supplied on the basis of needle nutrient content analyses. In total 1600 kg N/ha or in average 64 kg N/ha/year was supplied.

Growth of the unfertilized treatment increased from about 2,4 m^3/ha to about 5 m^3/ha during the experimental period (Figure 5). For the fertilized trees, growth increased much more rapid and was 24 m^3/ha in the last 4-year period, more than 4 times higher than the control. For the whole period, total stem growth of the fertilized trees was 377 m^3/ha, almost 4 times higher than for the control (97 m^3/ha). This corresponds to a total CO_2 capture of about 510 and 130 tons/ha, respectively, for fertilized and unfertilized trees.

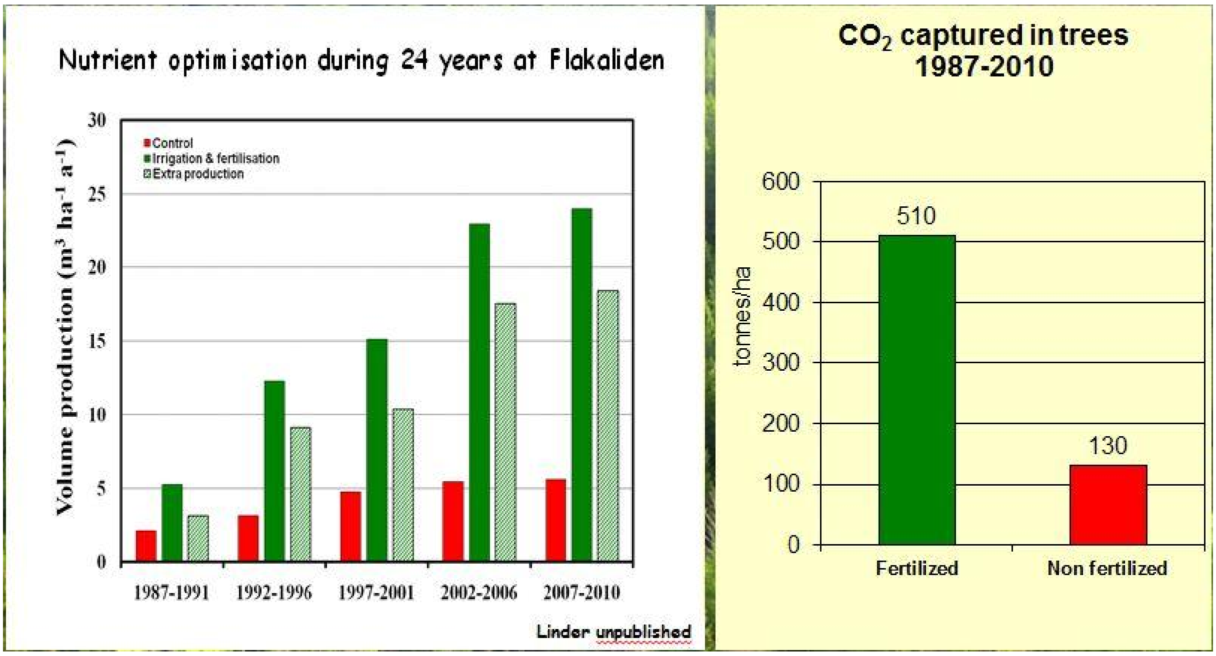


Figure 5. *Stem growth for untreated and annually nitrogen fertilized young Norway spruce in Flakaliden, northern Sweden*

Growth pattern and CO_2 capture for different management scenarios

Growth during one rotation

What would be the effect, if we could apply growth increasing "more needles" management during a whole rotation and let's say increase the average growth by 50% ? In Figure 6, the growth curves for the ordinary or standard practice management are shown in green. The solid line shows average growth and the broken line shows annual growth. Mean growth for the rotation period is 4 m^3/ha, corresponding to site index T22. The peak annual growth is about 6 m^3/ha and the optimal rotation period is 95 years. The yellow curves show growth increasing management, with 50% increased mean growth (i e, 6 m^3/ha, corresponding to site index T26). Peak annual growth reaches about 9 m^3/ha and optimal rotation period becomes 20 years shorter than for ordinary management. Total growth and harvested wood is 450 m^3/ha after 75 years. At that time the ordinary management production is 300 m^3/ha, which at optimal harvest time 20 years later, has increased to 380 m^3/ha.

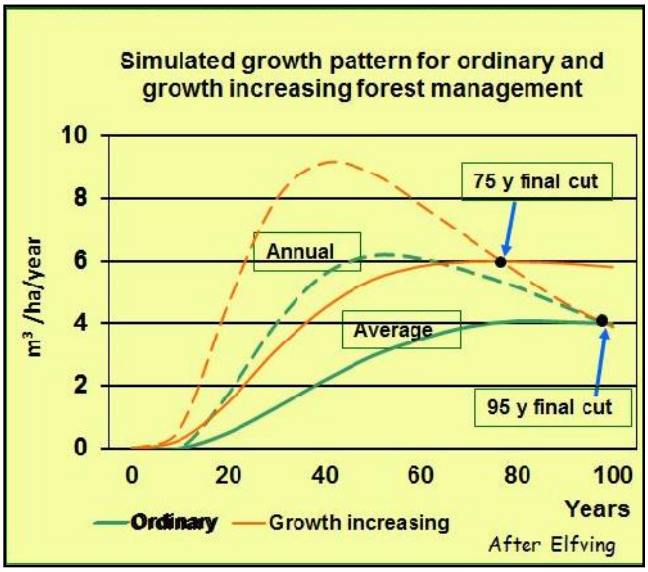


Figure 6. *Curves showing Scots pine annual and average growth for ordinary forest management (site index T22, green lines) and growth curves for a simulated increased growth (to site index T 26, yellow lines), using growth increasing forest management.*

Growth and CO_2 capture during 300 years

During the first rotation, annual growth peak will be at 40-60 years. If the forest is not managed with any cuttings, growth will slowly decrease and eventually approach zero in the very old forest, when the tress become very big and the needle mass is not sufficient for supply of sufficient photosynthetic products for tree growth (Figure 7).

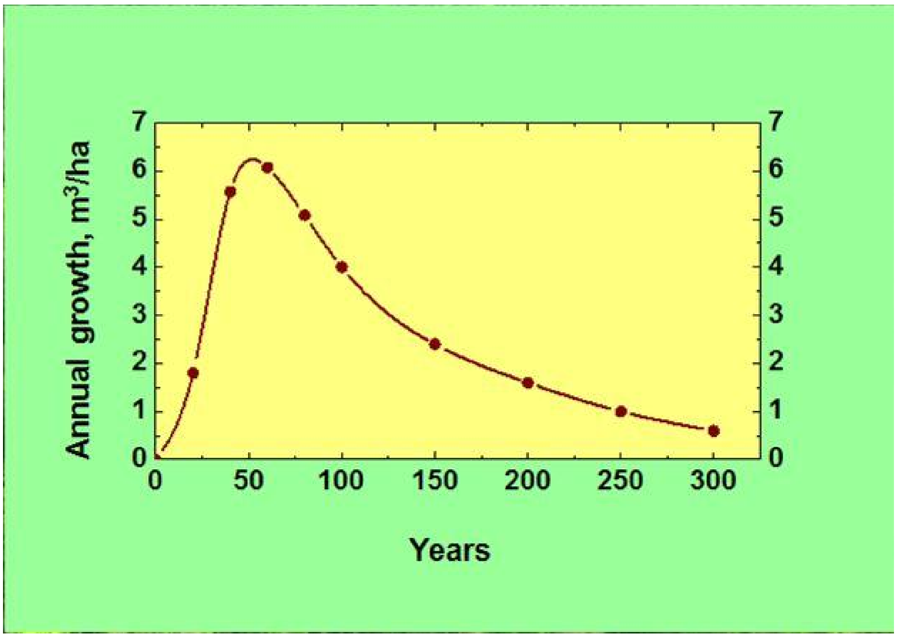


Figure 7. *Simulated annual growth for a Scots pine forest (site index T22) during 300 years, if no cuttings are carried out.*

The accumulated tree growth during 300 years may be simulated for three management examples; an unmanaged forest without cuttings, an ordinary managed forest and a forest managed with a 50% increased average growth in comparison with the ordinary management. For the unmanaged forest, the accumulated growth during the 300 year period will reach about 700 m^3/ha (Figure 8). In the example with ordinary management, three final cuts followed by regeneration will be carried out, after 100, 200 and 300 years, respectively. The total stem growth will amount to 1200 m^3/ha. For the growth increasing managed example, time between final cuts will be 75 years and total stem volume produced after 300 years, will be almost 1800 m^3/ha, more than double the amount for the unmanaged forest.

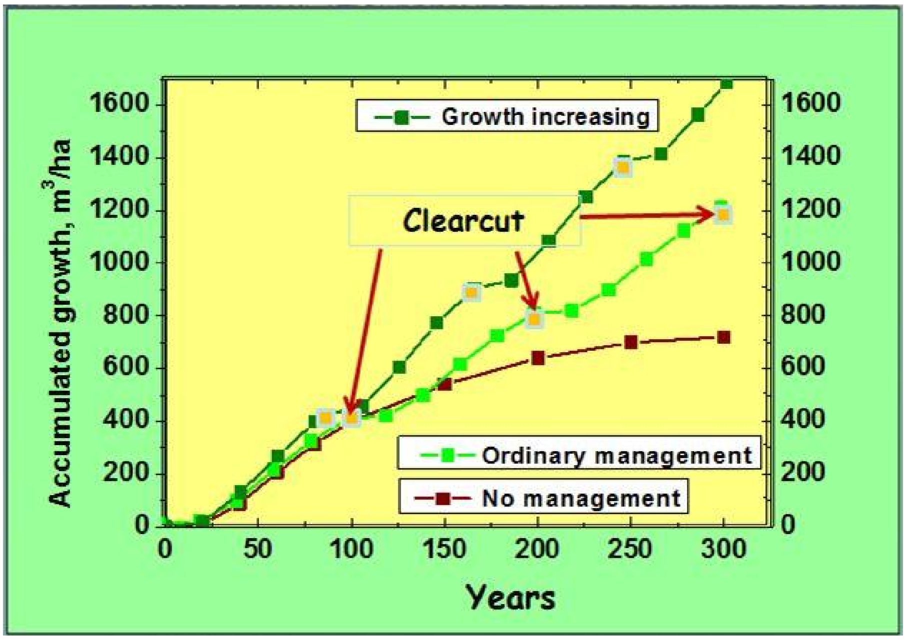


Figure 8. *Simulated accumulated growth during 300 years for three management scenarios.*

Total captured CO_2 in the tree biomass will be about 1000 tons/ha for the unmanaged forest, or in average 3 tons/ha/year (Figure 9). The growth increasing example will result in a CO_2 capture of more than the double with 2300 tons/ha, and in average nearly 8 tons/ha/year.

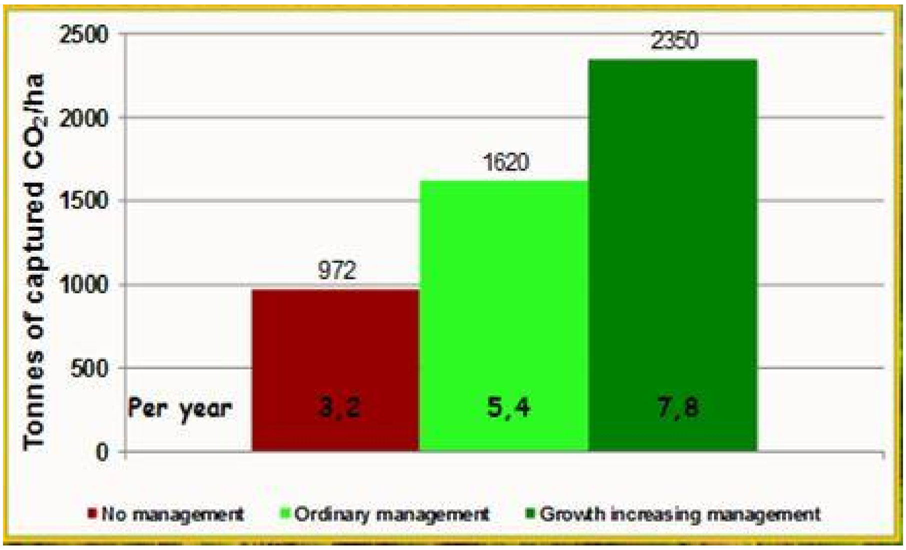


Figure 9. *Total captured CO_2 in the tree biomass for the three management examples.*

Tree biomass harvest after growth increasing management

With growth increasing forest management, the total produced stem volume will be 450 m^3/ha during the rotation. Tree biomass is harvested at three occasions, thinning after 35 and 55 years and final cut after 75 years (Figure 10). At the first thinning, all the above ground biomass of the trees is harvested as fuelwood to an amount of 30 tons dw/ha. At the second thinning and final cut, an equal amount of timber and pulpwood is harvested, in total 142 tons dw or 370 m^3/ha. In addition, also logging residues to an amount of 20 tons/ha are harvested as well as 30 tons/ha of stumps, in order to utilize the energy content in the “waste” biomass, instead of leaving it to decompose and release the captured CO_2 to the atmosphere. In total 222 tons/ha of tree biomass is harvested during the whole rotation.

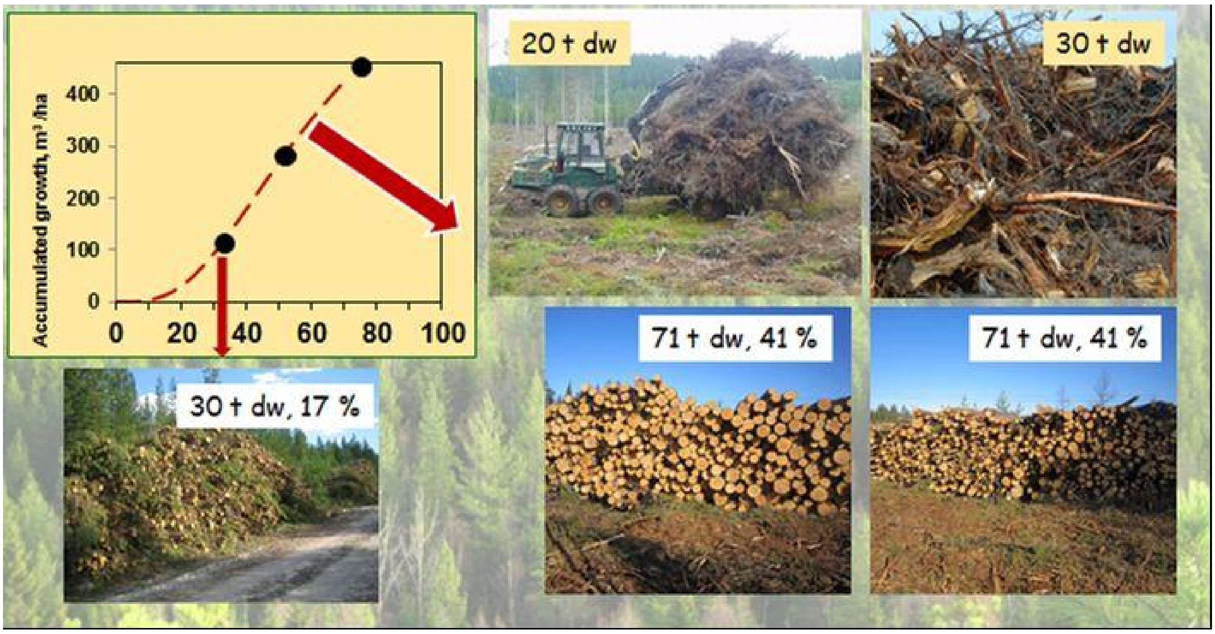


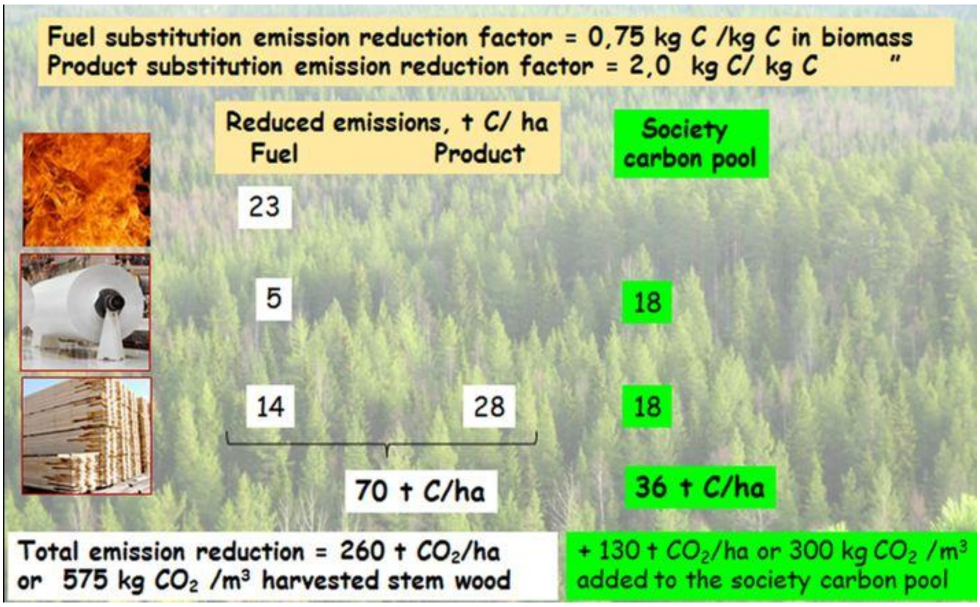
Figure 10. *Amount of tree biomass harvest/ha during one rotation for growth increasing forest management*

CO_2 effects of tree biomass use

Substitution of 1 kg C in fossil based raw material for production of energy or products with 1 kg C from tree biomass, will reduce CO_2 emissions with 0,75 and 2 kg C, respectively (Figure 11) (Sathre & O’Connor 2010). About 50% of the harvested tree biomass will remain in the produced paper and in the produced sawn goods. The rest will be used as fuel. For pulp and paper, the rest in form of lignin, black liquor and waste fibre is used entirely within the production process.

80% of produced paper and sawn goods is estimated to end up as fuel and substitute fossil fuels. 80% of sawn goods will substitute other material as steel and concrete, reducing CO_2 emissions by 28 ton C/ha. Totally reduced emissions are 70 t C or 260 t CO_2/ha or 575 kg CO_2/m^3 harvested stem wood.

In addition, the produced paper and tree products will be part of the society carbon pool for a certain time, before ending up as fuel or landfill. in this case, 36 t C/ha is added to this pool during the 75 year rotation. So, for each increased m^3/ha in growth, harvest and use, CO_2 emissions will be reduced by 575 kg and 300 kg CO_2 will be added to the society carbon pool.



- Figure 11. *Reduced CO2 emissions by substitution of fossil based raw material for energy production (fuel) and for material production (product) tree biomass based raw material.*

Conclusion

Conifer forest management for effective climate change mitigation means:

- increased tree growth and
- increased harvest of tree biomass,

facilitating an

- increased use of tree biomass for substitution of energy sources and products, based on fossile raw material, and an
- increased society carbon pool of tree based products

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