Swedish Environmental
Research Institute

Applying different silvicultural systems in Swedish forests

A model analysis of three scenarios

Report number: C11229
In cooperation with: University of Eastern Finland
Authors: Timo Pukkala (main author), Mikael Malmaeus, Eskil Mattsson (contributing authors)

Funded by: Formas

ISBN: 978-91-7883-826-4

Summary

This report presents a scenario analysis of three alternative forest management systems in Sweden: rotation forest management (RFM), continuous cover forestry (CCF), and a mixed system combining the two. Using a 75-year simulation framework, the Monsu forest planning software was applied to a large dataset of Swedish National Forest Inventory plots to model forest dynamics, timber production, carbon sequestration, and a broad range of ecological and multiple-use indicators. The simulations incorporated Swedish growth models, optimal schedule selection through combinatorial optimization, and assumptions about protected areas, harvesting constraints, and silvicultural practices.

The results include estimates of timber supply and assortment distribution, forest volume development, biomass accumulation, carbon balances and carbon stock dynamics, as well as indicators related to biodiversity, recreation, and non-wood forest products. Together, these outputs provide a comprehensive comparison of how different silvicultural strategies may influence both production-oriented and ecological outcomes over time, based on the assumptions applied in the simulations.

Overall, the scenarios indicate that while all systems can deliver a stable long-term timber supply, continuous cover forestry tends to enhance forest structural development, carbon storage, and several multiple-use values, whereas rotation forestry maintains a more substantial supply of pulpwood and biofuel. The mixed scenario generally yields intermediate results, illustrating how combining management approaches may balance economic and ecological objectives. Together, the findings offer insight into the trade-offs and synergies associated with transitioning toward more diversified forest management in Sweden.

Table of contents

1 Introduction

Continuous cover forestry (CCF) is gradually gaining popularity in Sweden and Finland. This change reflects the overall trend in Europe. The use of clear-felling is already prohibited or discouraged in several European countries, and the recent biodiversity strategy of the European Union highlights the need to explore alternative forest management approaches.

This report is part of the Formas research project *To create sustainable forestry to store carbon, adapt to a changing climate and contribute to biodiversity, employment, and recreation* (work package 2). The project includes scenario analyses on the effect of CCF on biomass production, carbon sequestration and storage, biodiversity, non-wood forest products, recreation, reindeer husbandry, and resilience to extreme weather and pests. It also aims to evaluate the effects of alternative forest management scenarios on economic value creation, labor markets, provisioning cultural and ecosystem services, and direct and indirect climate effects (carbon sequestration as well as impacts on Sweden's Roadmaps for fossil-free competitiveness).

This sub-report compared three alternative management options in Swedish forests: even-aged forest management (referred to as rotation forest management, RFM), clear-felling-free forest management (referred to as continuous cover forestry, CCF), and a combination of these two silvicultural systems. A 75-year scenario was developed for each management option. The scenarios provide information on the timber supply, forest development, carbon sequestration, multiple-use values, and biodiversity indicators in alternative forest management systems.

The analyses were conducted with the Monsu forest planning software using inventory plots of the Swedish National Forest Inventory (NFI) as input data. The Monsu software uses Swedish models for the diameter growth, height, and survival of trees, and the ingrowth (gradual natural regeneration) of the stands. The models are based on measurements of the permanent NFI plots from the periods 2011–2015 (1st measurement) and 2016–2020 (2nd measurement).

The details of the models and methods used in calculations are explained in a separate technical appendix. This report concentrates on presenting and comparing the model simulation results across the different management scenarios based on the assumptions applied in the simulations.

2 Methodology

2.1 Materials

The input data for the simulations consisted of plots from the Swedish National Forest Inventory (NFI) in 2016–2020. In the NFI, all trees with a diameter of breast height (dbh) with at least 4 cm were measured for species, diameter (dbh) and height.

Only plots that were located within a single stand were used as input data, i.e., plots located at stand borders were not used. All analyses were performed separately for three regions, referred to as South, Central and North Sweden, to enable analysis of how management systems perform under different ecological and climatic conditions:

- South Sweden: latitude < 60 degrees
- Central Sweden: latitude 60–64 degrees
- North Sweden latitude > 64 degrees

A random sample of 2000 NFI plots was selected separately for each geographical region. The site variables (latitude, altitude, site index) and tree variables (species, dbh, height) were imported to the Monsu forest planning system.

Each measured tree was given an expansion factor, representing the number of trees per hectare. The expansion factor was 259.84 for trees with dbh between 4 and 9.99 cm (these trees were measured within a 3.5-meter radius), and 31.83 for trees with dbh ≥10 cm (measured within a 10-meter radius).

2.2 Production of the scenarios

Three forest management scenarios were analysed:

1. 0% CCF, 20% protected, 80% RFM (rotation forest management)
2. 33% CCF, 20% protected, 47% RFM
3. 80% CCF, 20 % protected, 0% RFM

In scenario 2, the NFI plots were assigned optimally to protection, CCF, and RFM. In Scenarios 1 and 3, the NFI plots were optimally assigned to protection or management. Optimality means that economic profitability is maximized while meeting the regional constraints set to protection, timber supply, and average growing stock volume.

The scenarios were produced in two steps. First, alternative management schedules were simulated for the NFI plots for 75 years. The 75-year period consisted of five 5-year periods followed by five 10-year periods. Second, the optimal combination of the simulated management schedules was found, using combinatorial optimization.

Only RFM was simulated in Scenario 1, and only CCF management was simulated in Scenario 3. In Scenario 2, both RFM and CCF management schedules were simulated for each NFI plot. Alternative schedules were obtained by postponing the cutting by one of several 5- or 10-year periods from the earliest possible moment or excluding all cuttings at a certain period (first, second, third, etc.). A no-cutting scenario was also simulated for every plot. The average number of simulated management schedules ranged from 12.5 to 32.2 per plot, depending on the scenario and region (Table 1).

Table 1. Average number of 75-year management schedules simulated for the NFI plots.

Region	RFM	RFM+CCF	CCF
South Sweden	15.4	32.2	17.8
Central Sweden	14.3	28.2	14.9
North Sweden	14.4	25.8	12.5

The simulation used Swedish models for diameter increment, tree survival, and ingrowth (see Appendix). Biomass and volume were calculated by Finnish models, using tree species, dbh, and height as predictors. It may be assumed that the relationships are quite similar in Sweden and Finland.

Some other models used in simulation were also based on Finnish data (models for wild berries, mushrooms, scenic beauty). The decomposition of dead organic materials (dead trees, harvest residues, litter) was simulated using the Yasso model. Yasso is a global model that has been used in several countries, and it is therefore expected to work equally well in Sweden and Finland.

In the second step, the ideal combination of simulated management schedules was found by using combinatorial optimization. First, net present value (NPV) with a 3% discount rate was maximized in RFM under the constraint that 20% of the forest area must be protected, and the total growing stock volume should never fall below 95% of the initial volume (in 2025). This constraint prevented too heavy cuttings during the first 5-year period.

The average annual harvest was calculated from this solution. Then, an additional constraint was added to the optimization problem requiring that the annually harvested volume must be at least 80% of the average harvest. These constraints guaranteed a reasonably constant timber supply but allowed the solution to depend on the properties of the forests and the selected silvicultural system.

The net income from harvests was calculated as the difference between roadside timber prices and harvesting costs. Calculation of the harvesting cost was based on the time consumption functions of the harvesters and the forwarders, accounting for factors such as removal per hectare, mean size of the harvested trees, cutting type (clear-felling vs. partial cutting), distance between strip roads (20 m assumed), and forwarding distance (200 m assumed). The harvesting cost was calculated, separately for each cutting, by multiplying the time consumption of the machine by its hourly cost.

A 20% tree breeding benefit was assumed for planted trees (trees planted during the 75-year simulation); the prediction of the diameter increment model was multiplied by 1.2. A "thinning stress" was assumed after thinning from above. A 20% reduction in diameter growth was made during the first 5-year period after thinning, and a 10% reduction was made during the second period. In all partial cuttings, damage to small trees was simulated. The proportion of damaged trees increased with increasing tinning removal.

It was assumed that protected forests should have a reasonable growing stock volume. The mean initial volume (in 2025) of the protected forests had to be at least 250 m^3/ha in South Sweden, 210 m3/ha in Central Sweden, and 170 m^3/ha in North Sweden.

3 Results

All the results are based on a sample of 2000 randomly selected plots in each region. The results are reported as per hectare.

3.1 Timber supply

The mean annual stem wood harvest (m^3/ha per year) was calculated for forests that were not protected (80% of the area). Protection decreased cutting possibilities significantly since protected forests had a reasonably high volume (250/210/170 m^3/ha in South/Central/North Sweden).

The mean annual timber harvest was fairly similar in all three management scenarios (denoted as RFM, FRM+CCF, and CCF in Figure 1). However, increasing the use of CCF greatly decreased the supply of pulpwood. CCF increased the supply of large sawlogs.

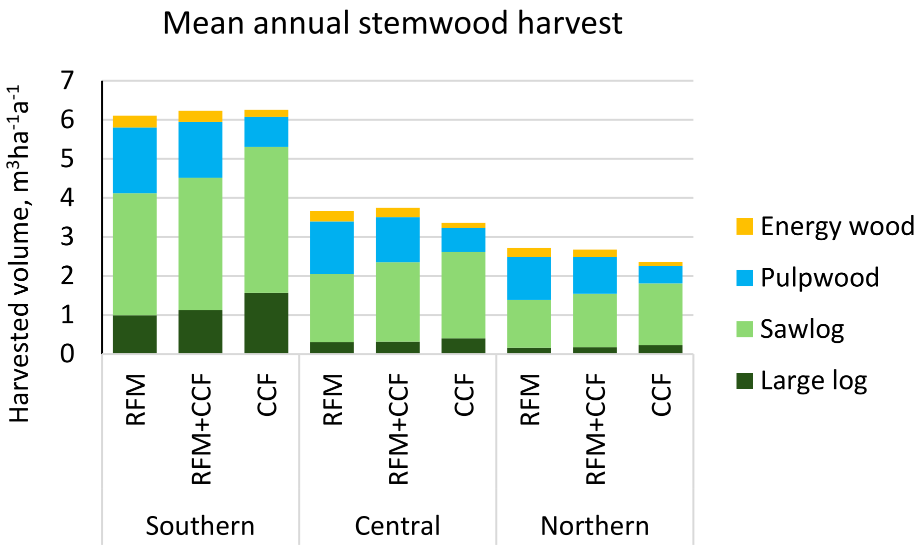


Figure 1. Mean annual stem wood harvest. A large log is a sawlog with a top diameter of 28 cm or more. Energy wood is stem wood harvested for bioenergy.

It was assumed that branches and treetops are harvested for biofuel in clear-felling sites with a 65% harvest rate in South Sweden, 40% in Central Sweden, and 20% in North Sweden. The average annual biofuel harvest for different regions and scenarios is shown in Figure 2. Under these assumptions, an increased share of CCF is associated with lower biofuel harvest levels.

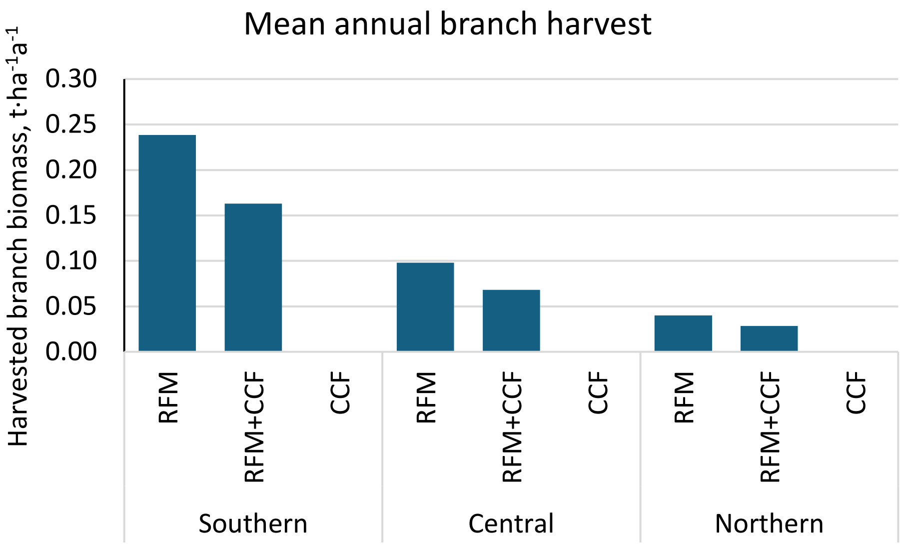


Figure 2. Mean annual biofuel harvest (from branches and tree tops), assuming that biofuel is collected only in clear-felling, and the harvest rate is 65% in South Sweden, 40% in Central Sweden, and 20% in North Sweden.

The mean annual harvest of different 5-year or 10-year periods (Figure 3) shows heavy cuttings during the first 5 years in RFM, which is logical since there are stands (and NFI plots) where the age and diameter limit for the economic maturity had already been passed, i.e., the cutting was late in economic sense. The cutting peak of the first period was less pronounced in CCF.

The harvest of large logs decreased with time in RFM. In contrast, CCF maintained the supply of large logs, especially in South Sweden. Pulpwood harvest was constantly low in CCF throughout the simulation period.

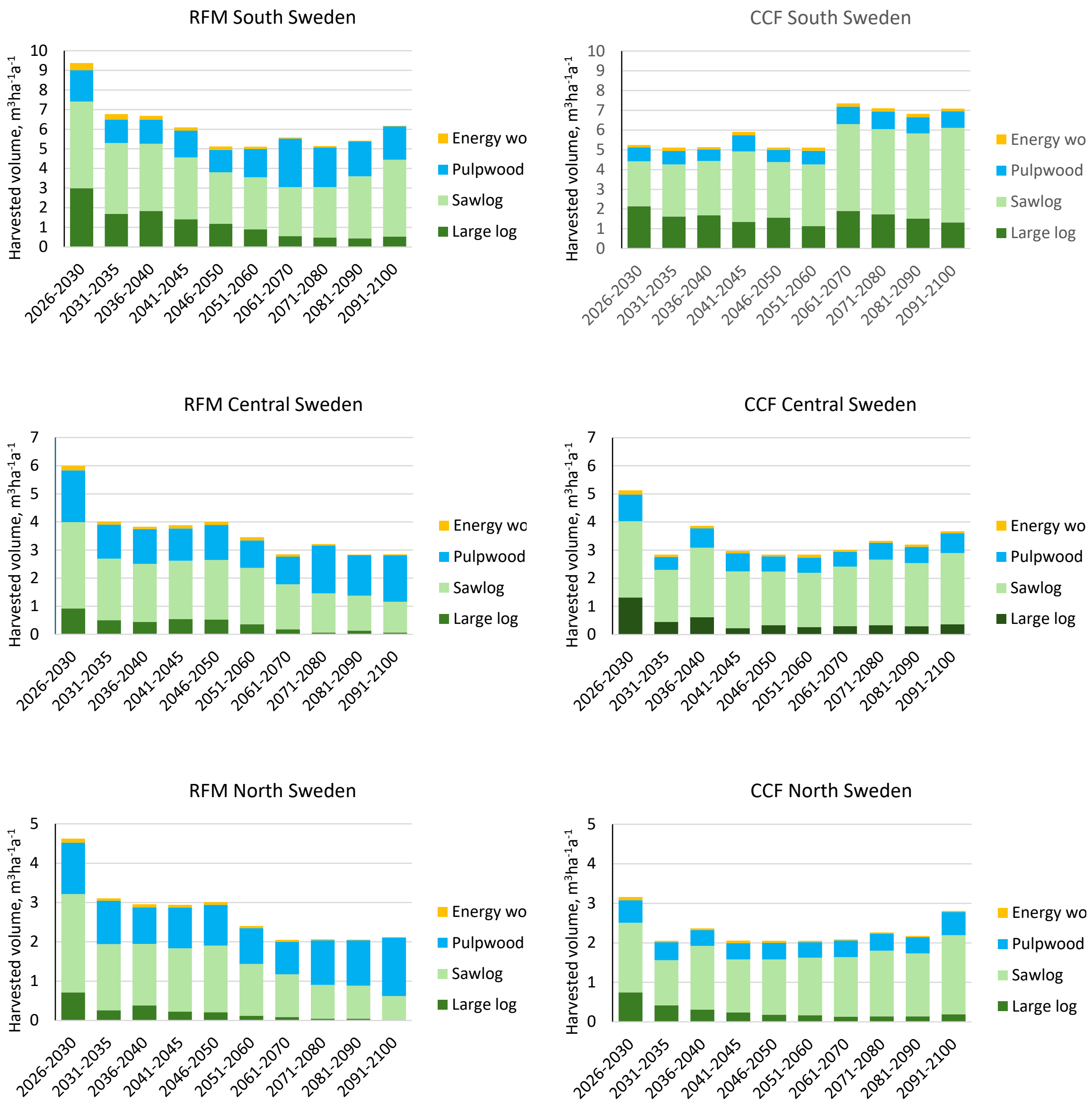


Figure 3. Periodical harvest of different timber assortments in RFM and CCF. The results are calculated as per hectare and year of non-protected forest.

The volume production (yield) of different scenarios was calculated as the sum of harvested volume and the change of growing stock volume during the 75 years. Figure 4 shows that the volume production increased with increasing use of CCF under the assumptions applied in the simulations.

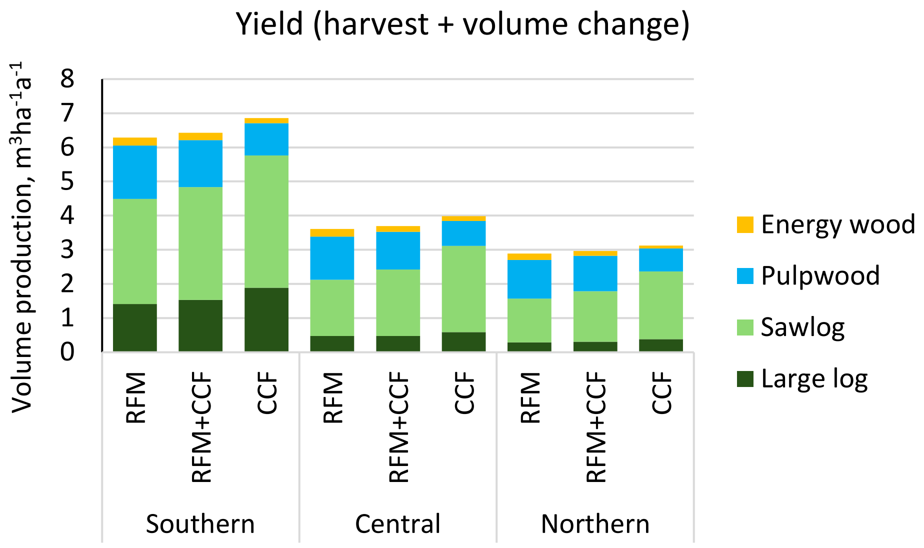


Figure 4. Net volume production (harvested volume plus change of growing stock volume). The growing change in the stock volume includes only live trees (therefore, "net volume production"). The calculation includes both protected and non-protected forests.

The average annual net income (cash flow) was the largest in the CCF scenario (Figure 5), which is logical since the harvests in this scenario consisted of more valuable timber assortments (more large logs and sawlogs, less pulpwood and biofuel), and the silvicultural costs were much lower than in RFM.

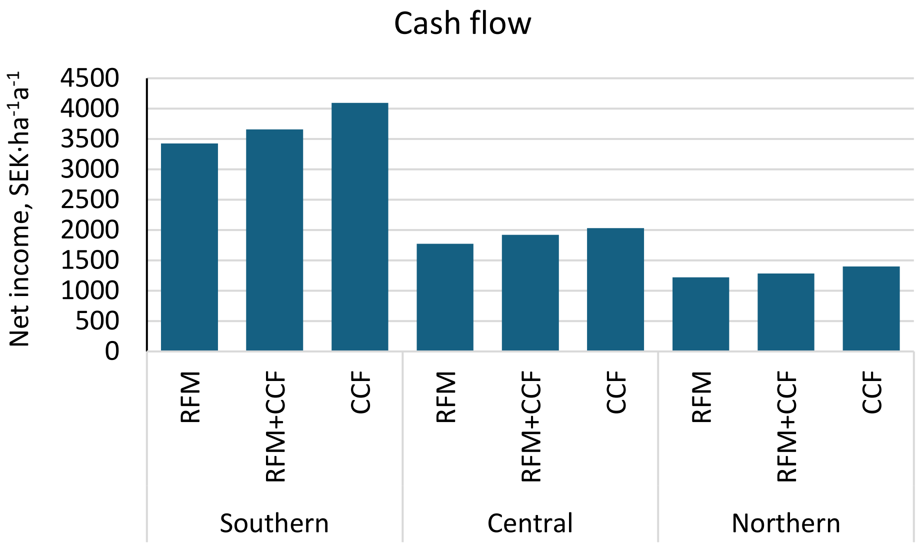


Figure 5. Mean annual net income in different management scenarios and geographical regions. The calculation includes only non-protected forests.

3.2 Cutting types in Scenario 2

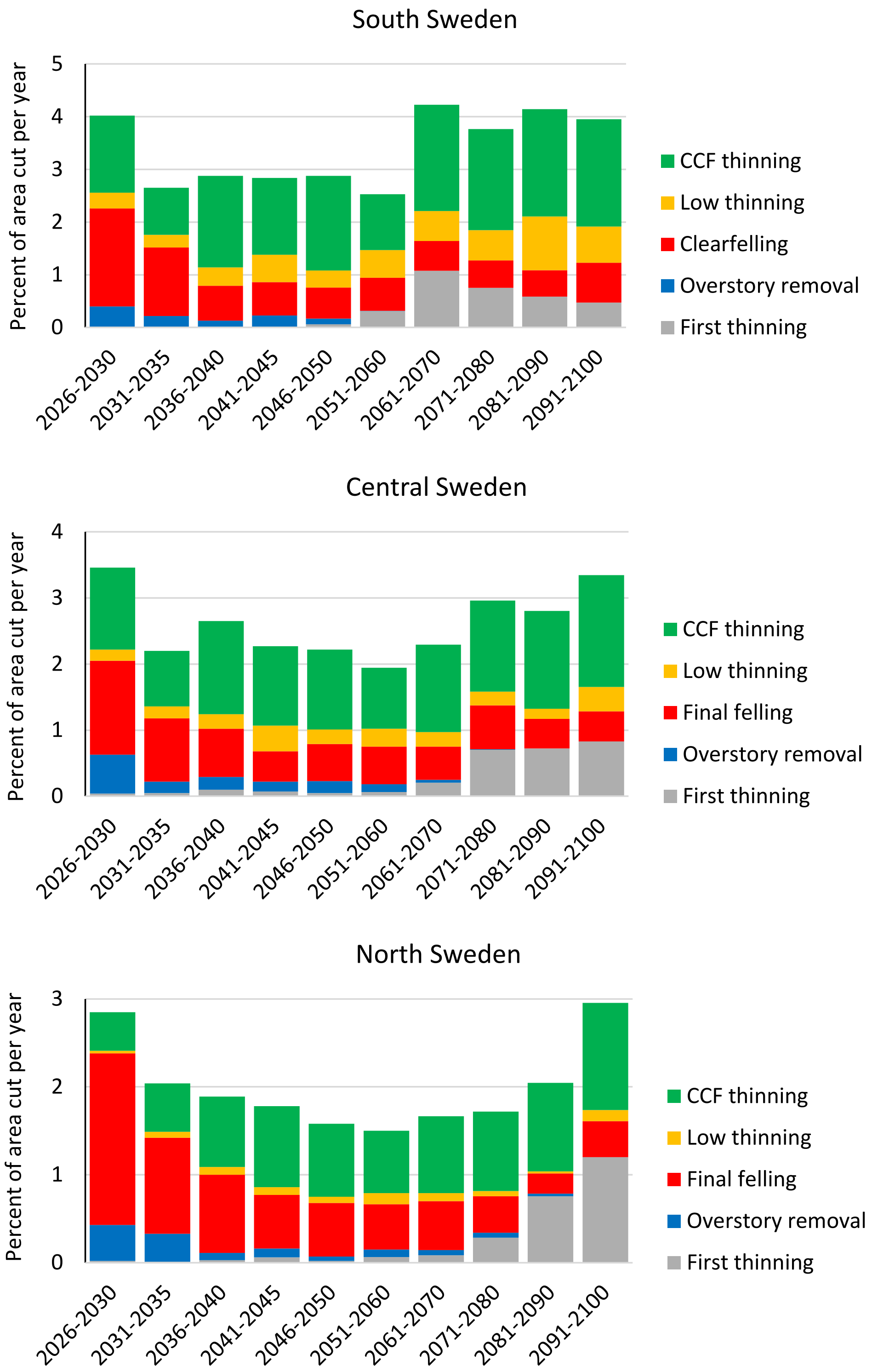


Figure 6. The areas of different types of cuttings in Scenario 2, expressed as the percentage of the total area cut in one year.

In Scenario 2, both RFM and CCF management options were allowed in every NFI plot, and optimization assigned the plots to RFM, CCF, or protection. The share of protected plots (plots that had no cutting during 75 years) had to be at least 20%, and 33% of the plots should be treated with CCF. The simulated thinning type in RFM was thinning from below, and the most common type of CCF-thinning was thinning from above.

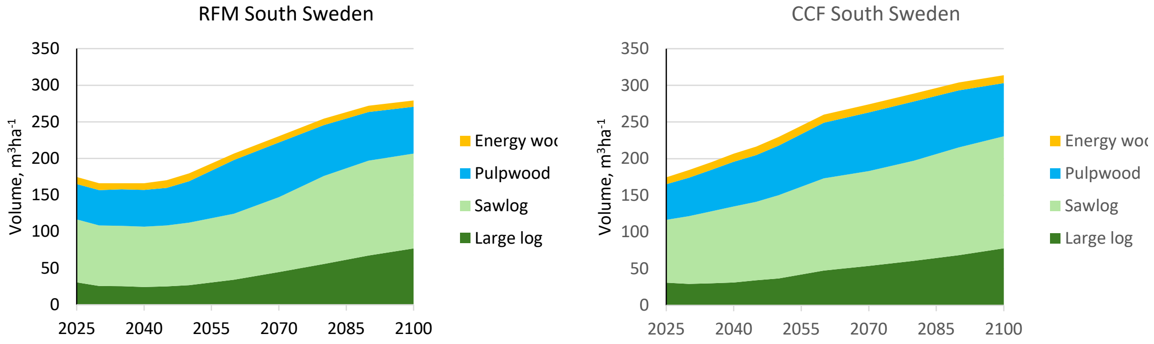
The results of Figure 6 indicate that the low thinning area (thinning from below) was relatively small, although low thinning was the only thinning type simulated in RFM, and 47% of the area was assigned to RFM. The explanation is that dense stands, where thinning was topical, were assigned to CCF. Under the model assumptions, this made it possible to use high thinning (thinning from above), which is clearly more profitable than low thinning. Two-storied stands should be treated with the removal of the upper storey, which is also a profitable treatment.

Over the simulation period, the area subjected to clear-fellings decreased, while the area managed with CCF-cuttings (usually thinning from above) increased. The area of the first commercial thinning (grey colour in Figure 6) increased towards the end of the 75-year simulation period. These are the first commercial thinnings of the plantations established in clear-felled areas of the first simulation years. They represent RFM management and are thinning from below.

3.3 Volume development

Figure 7 shows the development of the mean merchantable stem volume of live trees (m^3/ha). The volume development was more favourable in CCF, especially in Central and North Sweden. The increasing trend in volume was mainly explained by protection (20% of the forest was protected). The growing stock volume of the non-protected forests did not increase much.

Retention trees are not included in the diagrams of Figure 7. Retention trees were left in all clear-fellings of RFM. Some large trees were always left unharvested also in CCF (the maximum harvest rate for large trees was 90%), but these trees were not assigned as retention trees.



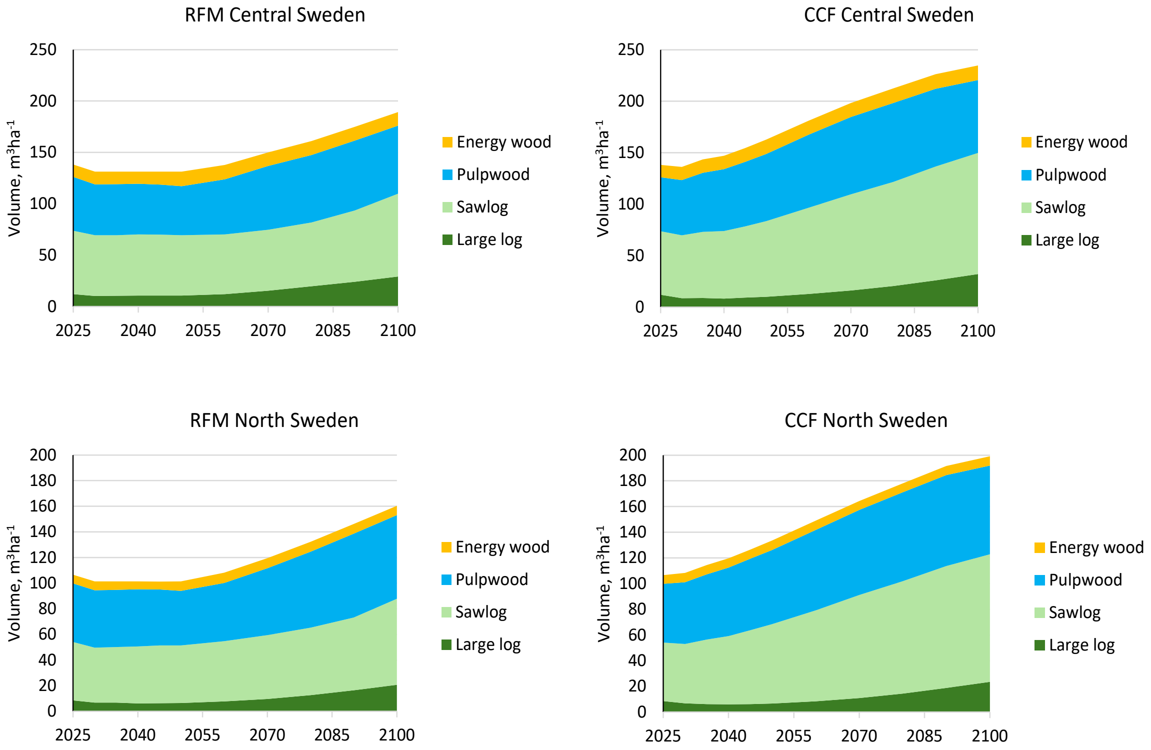


Figure 7. Development of the mean growing stock volume of merchantable live trees (retention trees left in clear-felling sites in RFM are not included).

3.4 Biomass

Figure 8 shows the development of the biomass of living trees (t/ha), separately for Scots pine, Norway spruce, and all the other species combined. These diagrams also include the retention trees. In Central and Northern Sweden, the biomass increased faster in CCF than in RFM, i.e., the difference was not explained by the retention trees of RFM. Faster biomass accumulation in CCF indicated a stronger carbon sink.

An increasing share of spruce can be seen in both silvicultural systems, but the trend was not more pronounced in CCF. In both systems, the species proportion can be modified by management (planting, thinning), which means that the results of Figure 8 are not obligatory outcomes from the use of different silvicultural systems.

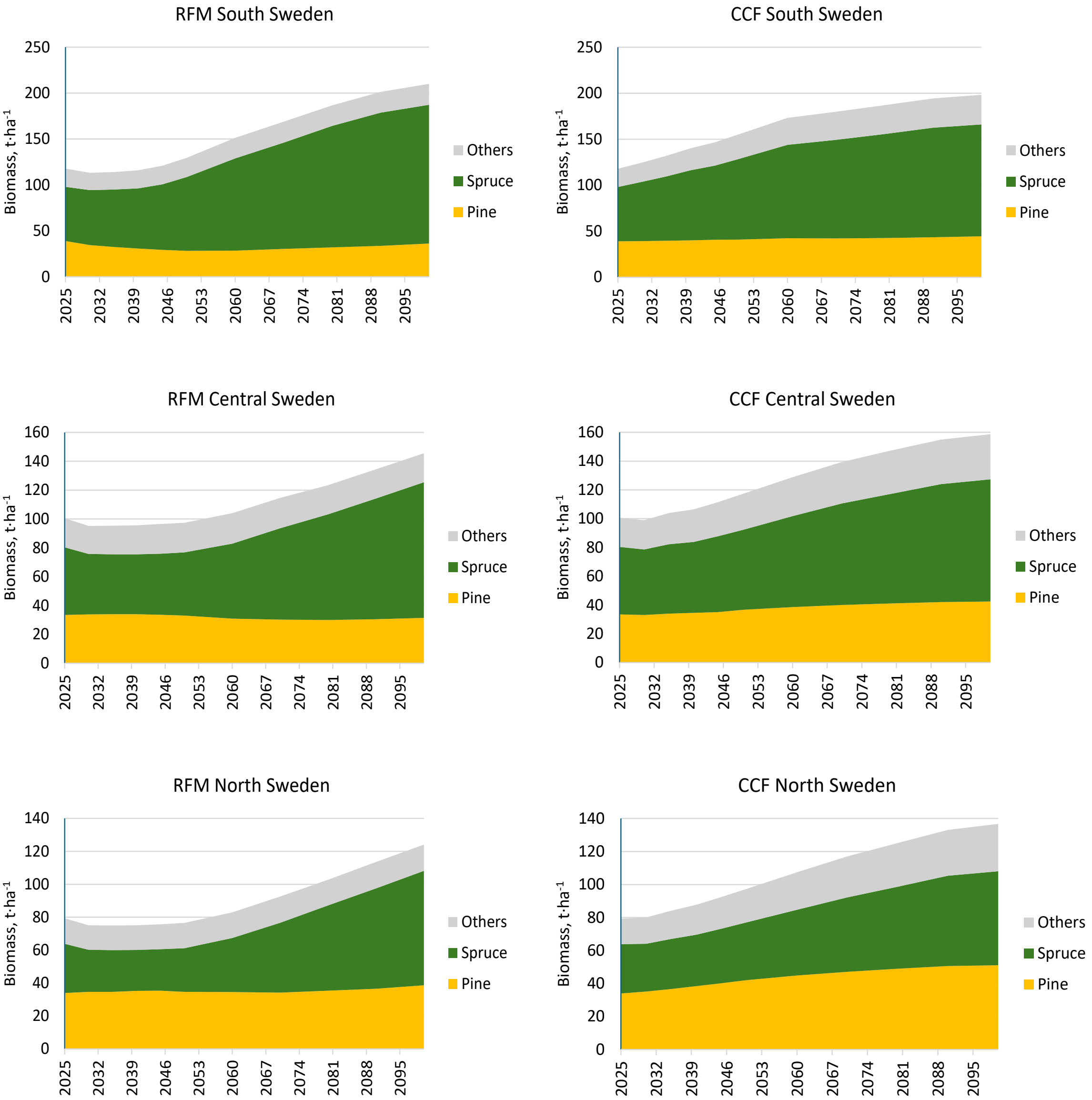


Figure 8. Biomass development in RFM and CCF. Retention trees included. The biomass includes the stems, branches, foliage and roots of living trees.

3.5 Carbon balance

The results for the mean carbon sink (Figure 9), expressed as tons of CO_2 per hectare and year, indicated that CCF clearly increased carbon sequestration in Central and North Sweden (positive carbon balance = carbon sink). Most of the CO_2 sink was accounted for by the increasing biomass of live trees, which was mainly due to the 20% protection.

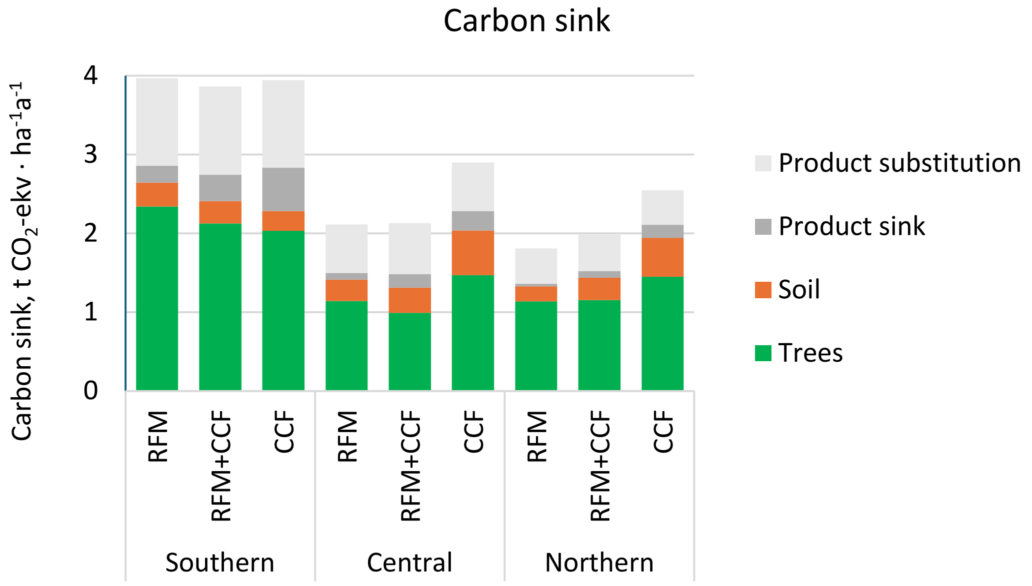


Figure 9. Mean annual CO_2 balance (positive value = sink) in different regions and management systems. The CO_2 balance consists of the CO_2 sink of trees, dead organic materials (DOM) and harvested wood products (HWP), and the substitution effects of wood-based biofuel and wood products.

Most of the carbon balance was explained by the increasing tree biomass, which in turn was mainly explained by the assumed share of protected forest. The second-most important component was the substitution effects of wood-based energy and products, representing avoided fossil emissions. The calculations used a decreasing trend in the substitution effects based on the assumption that energy sources and materials that compete with wood and tree biomass are gradually decarbonized (see Appendix for details).

The results indicate that wood products are a weak carbon sink (Product sink in Figure 9), and their effect on carbon balance is much smaller than the effect of fossil substitution. However, it should be noted that substitution effects cannot be included in international greenhouse accounting reports. In addition, the calculation of future substitution effects includes much uncertainty and many assumptions.

3.6 Carbon stocks

The temporal development of the carbon stocks of living tree biomass, DOM (denoted as "soil" in Figure 10), and wood products was more favourable in CCF than RFM, especially in Central and North Sweden. Figure 10 shows that the primary reason for the favourable CO_2 balance is the increasing carbon stock of live trees in protected forests. The carbon stocks of wood products are small compared to those of live trees and DOM (soil).

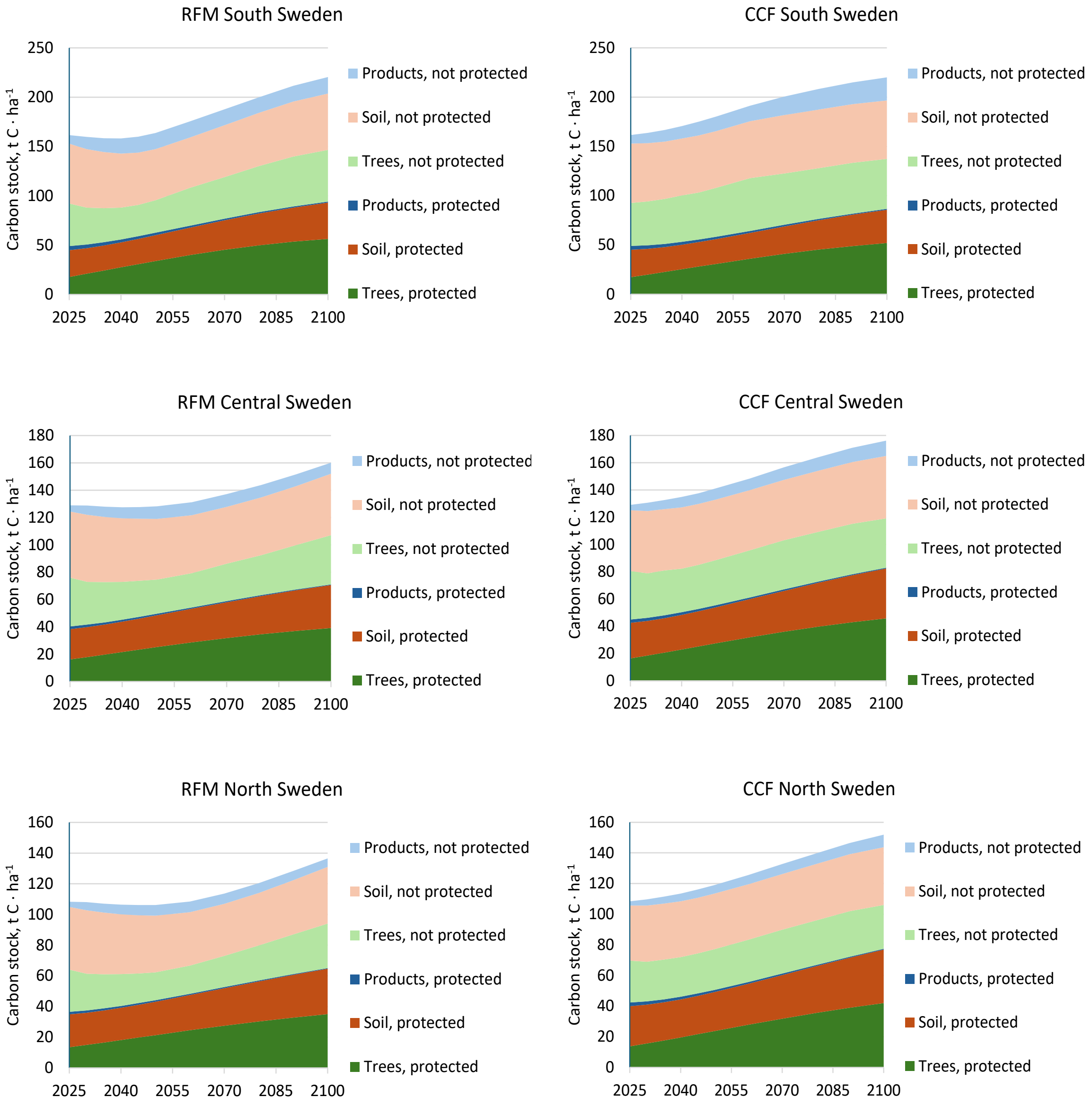


Figure 10. Development of the carbon stocks (tons of carbon per hectare) in different regions and management systems.

3.7 Product carbon stocks

The development of the carbon stocks of wood products and biofuel is shown in Figure 11. Almost all carbon was in the product category "sawn wood, plywood and veneer". Much of the harvested biomass is used for pulp products and bioenergy. However, because they are not durable products, their carbon stocks are small. The scenario calculations suggest that CCF management offers possibilities to increase the product carbon stocks for several decades. This is mainly explained by the greater harvest of sawlogs and other long-lived product categories, such as plywood and veneer logs.

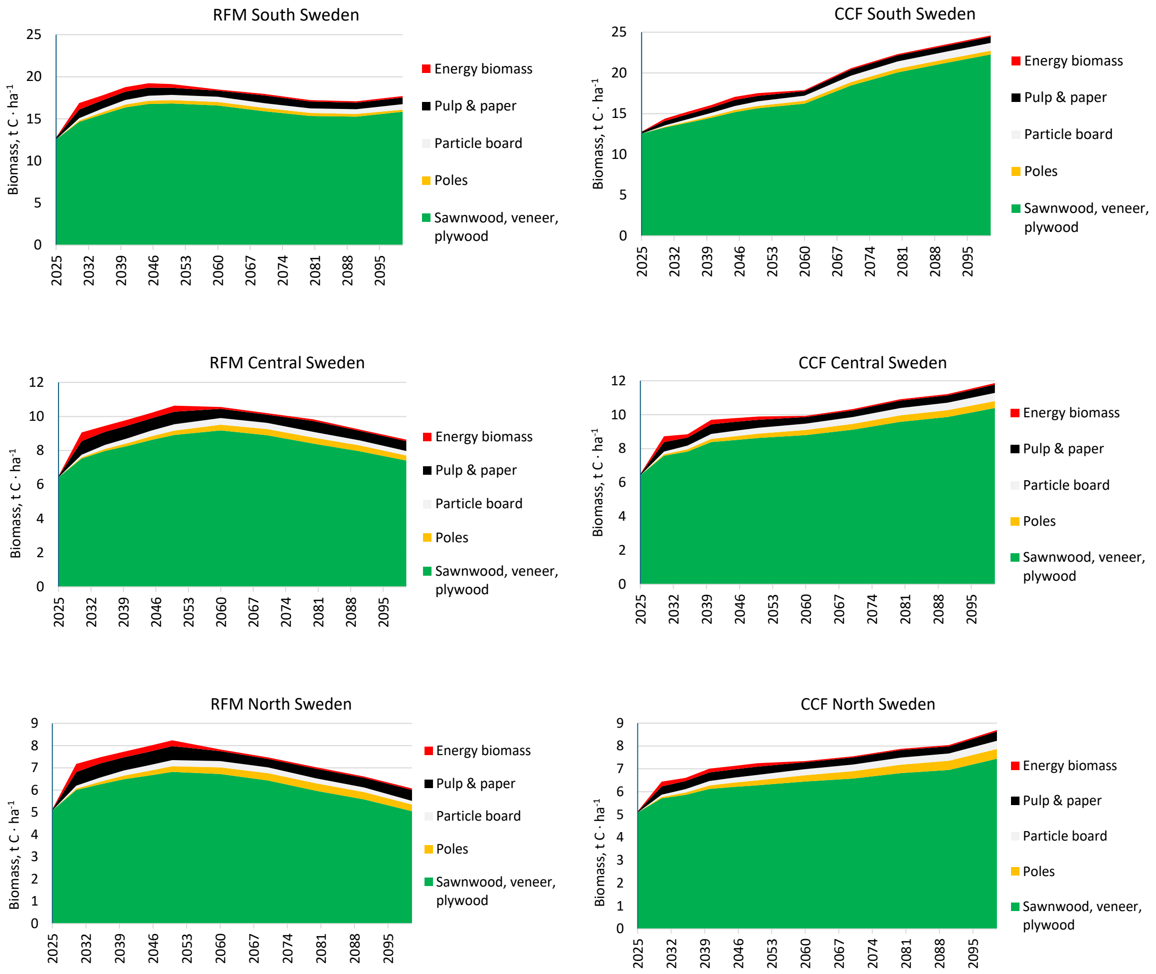


Figure 11. Development of the carbon stocks of wood products and energy biomass (tons of carbon per hectare) in different regions and management systems.

3.8 Multiple-use indicators

The scenic beauty index shown in Figure 12 describes the “within-forest” amenity (when people walk in the forest; the score does not describe the beauty of distant views). In all three geographical regions, CCF resulted in better scenic amenity values than RFM.

The results were the same for bilberry yields (Figure 13). On the other hand, the scenario calculation did not indicate any major differences between the management systems in lingonberry or mushroom yields (Figures 14 and 15).

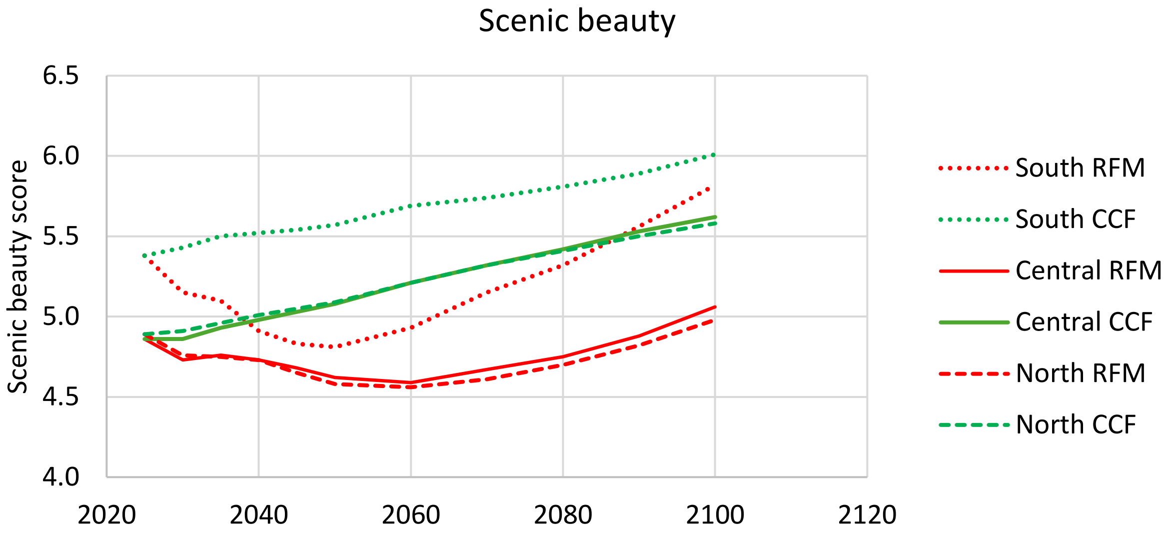


Figure 12. Development of the scenic beauty score in RFM and CCF in different regions. The scale of the score is 0 10. See the appendix for the formula for the scenic beauty score.

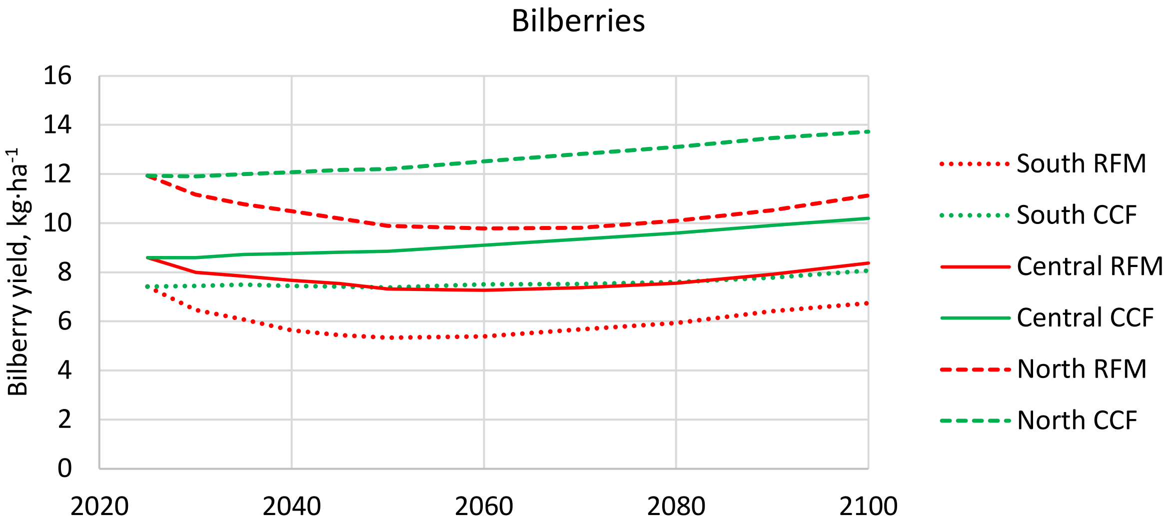


Figure 13. Development of mean annual bilberry yield in RFM and CCF in different regions. See the appendix for the formula for the bilberry yield.

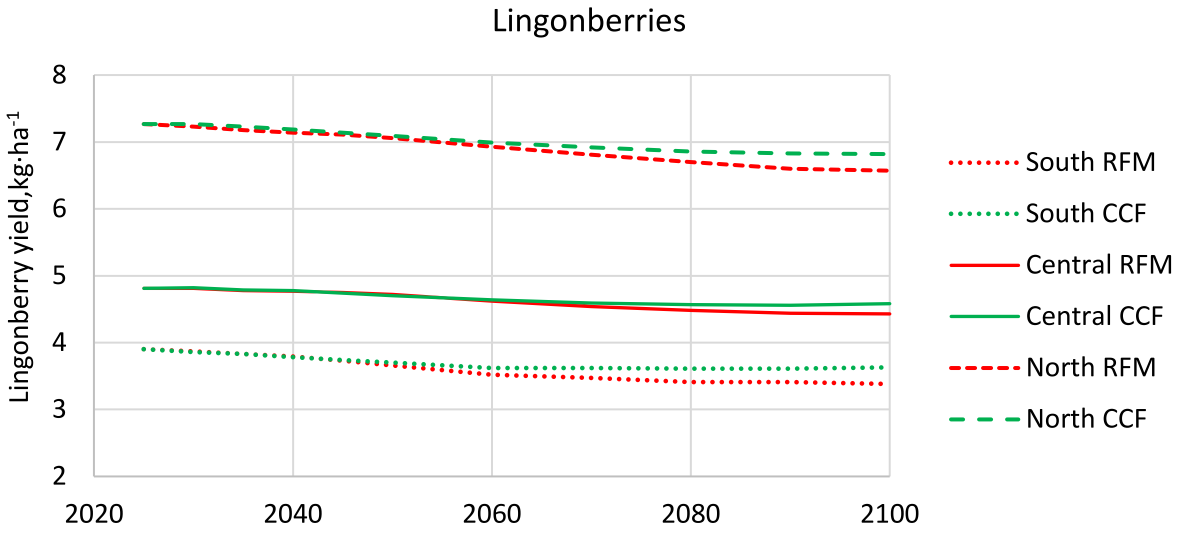


Figure 14. Development of mean annual lingonberry yield in RFM and CCF in different regions. See the appendix for the formula for the bilberry yield.

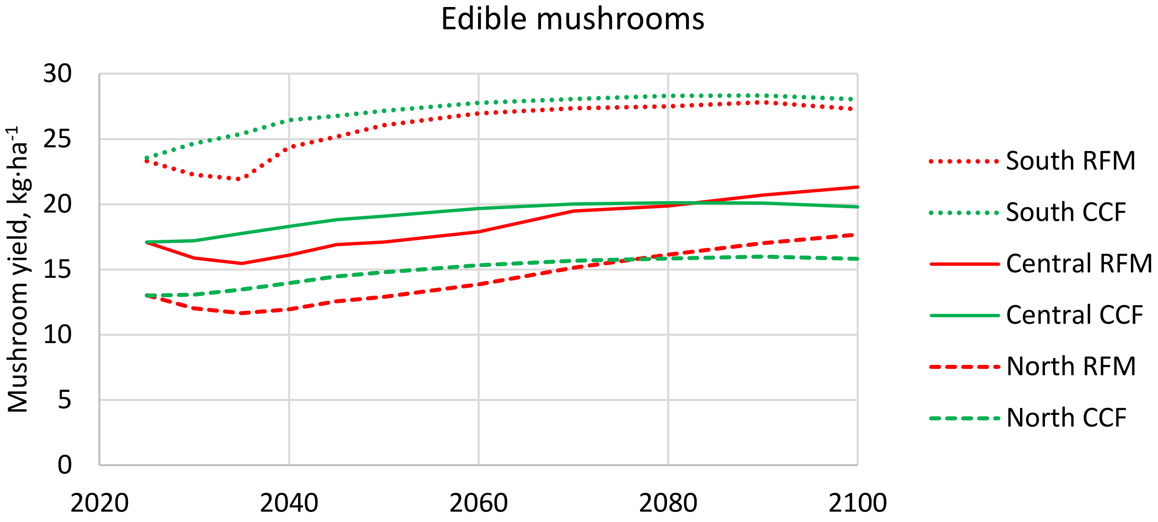


Figure 15. Development of mean annual lingonberry yield in RFM and CCF in different regions. See the appendix for the formula for the bilberry yield.

3.9 Biodiversity indicators

The volume of broad-leafed tree species increased in CCF and remained at a constant level in RFM (Figure 16). However, the species composition can be affected by management in both silvicultural systems (planting, tending, and thinning), which means that the results shown in Figure 16 are not the only possible outcomes of certain silvicultural systems.

As one objective of CCF is to favour mixed stands, the CCF cuttings were simulated so that if the proportion of a species was less than 5% of the stand basal area, that species was not removed at all. This modelling assumption may be one reason for the higher broadleaf volume of CCF.

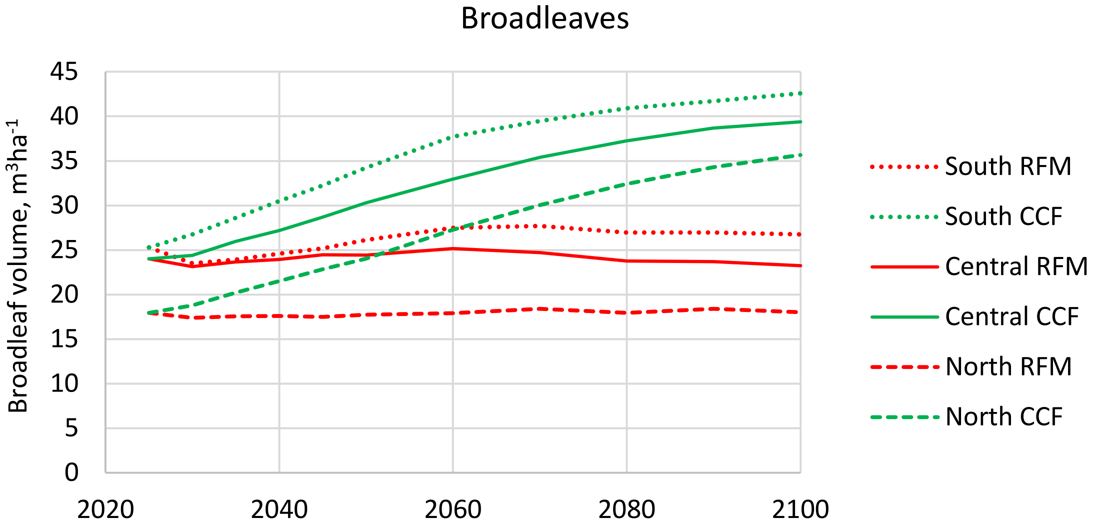


Figure 16. Development of mean broadleaf volume in RFM and CCF in different regions.

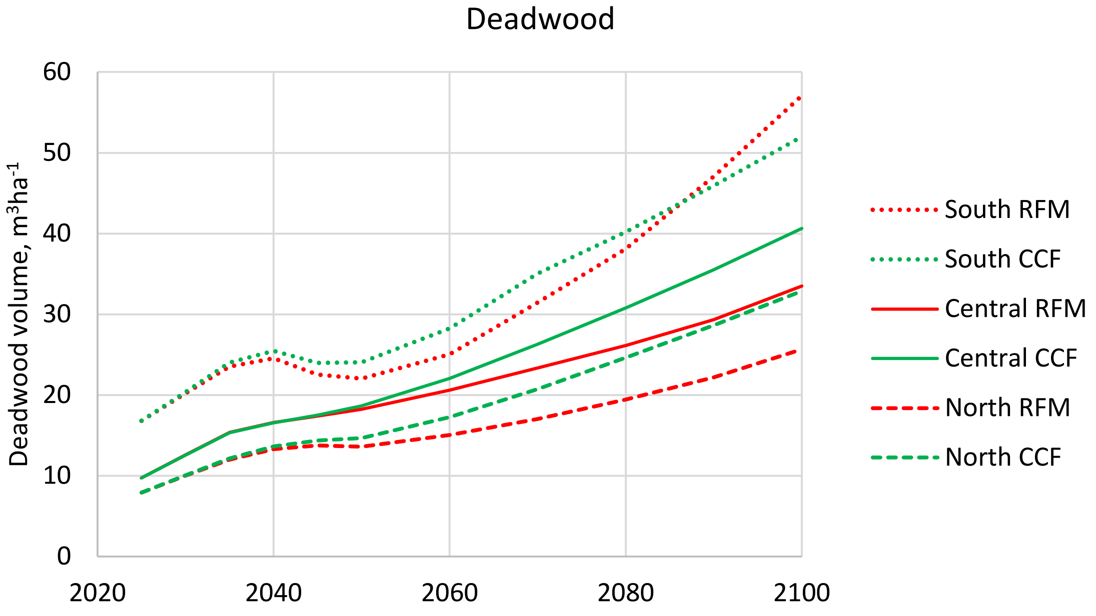


Figure 17. Development of mean deadwood volume in RFM and CCF in different regions. See the appendix for information on the calculation of deadwood volume.

The volume of the stems of dead trees increased in all scenarios, and there were no large differences between RFM and CCF (Figure 17). A significant reason for the increase might be the assumption that 20% of the forest area is protected, as well as by the modelling assumption that dead trees are not removed (for instance, for firewood).

There were no large differences between RFM and CCF in the volume of large trees (Figure 18). The increasing trend and the lack of differences may be explained by the protected forest areas, where large trees can accumulate over time. In addition, retention trees were left in RFM, and CCF cuttings left a minimum of 10% unharvested from the largest diameter classes, further contributing to the observed patterns.

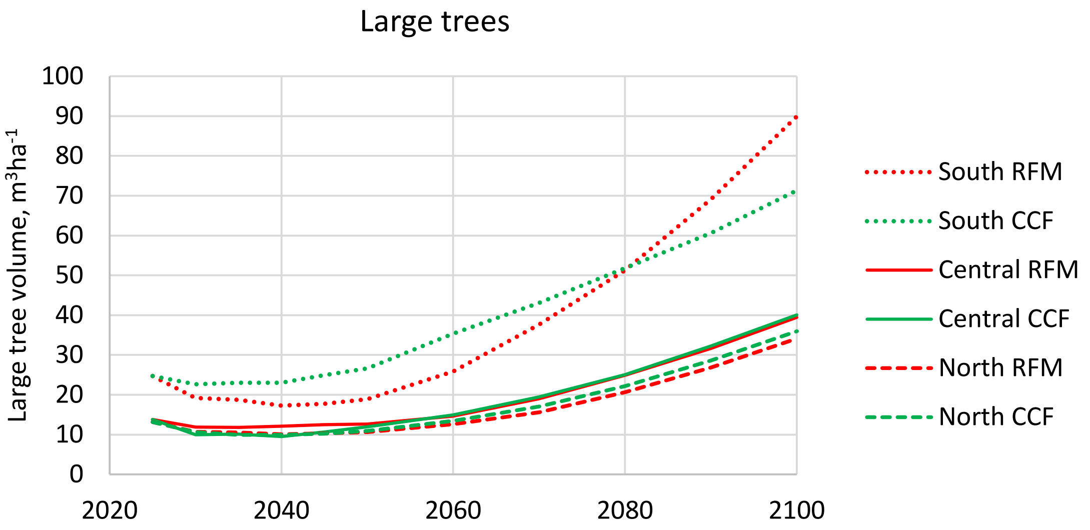


Figure 18. Development of the volume of large trees in RFM and CCF in different regions. See the appendix for information on the calculation of large tree volume.

The average species diversity (Shannon index) was better for CCF than RFM in North Sweden, but slightly worse in Central and South Sweden (Figure 19). It should be noted that species diversity can be affected by management in both silvicultural systems, meaning that a certain system is not automatically better than the other. Although the volume of broadleaves increased in CCF and remained constant in RFM (see Figure 16), CCF was not better than RFM in terms of the Shannon index in Central and South Sweden.

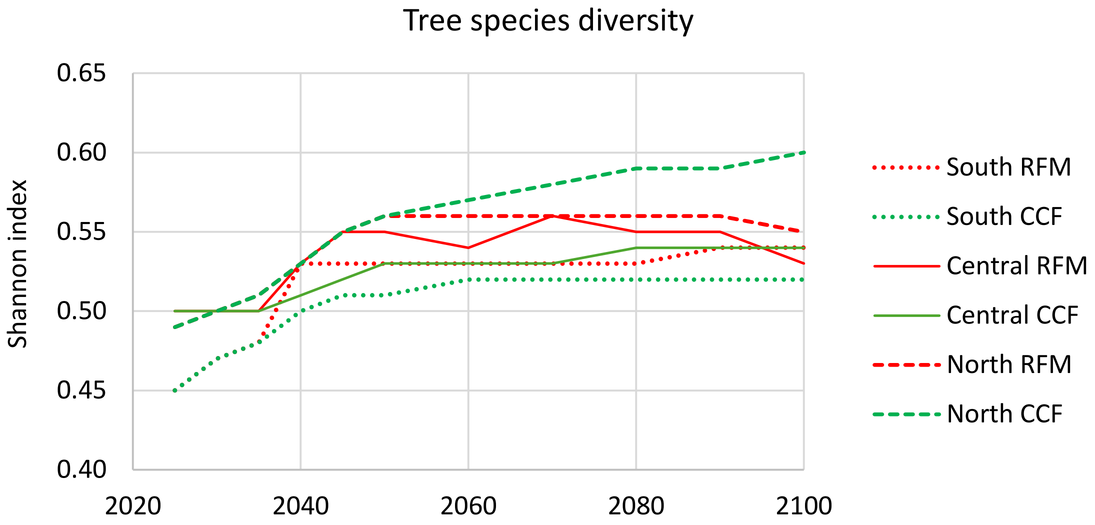


Figure 19. Development of the mean Shannon index of the NFI plots in RFM and CCF in different regions. See the appendix for information on the calculation of the Shannon index.

4 Conclusion

The scenario analysis indicates that the choice of silvicultural system has clear implications for timber supply, forest development, carbon dynamics, and multiple-use and biodiversity indicators. While all scenarios delivered a relatively similar overall timber harvest, increasing the share of CCF shifted the assortment structure toward more valuable large sawlogs and reduced the supply of pulpwood and biofuel. CCF also yielded the highest net incomes due to lower silvicultural costs and a greater share of high-value timber assortments.

Forest structural development and biomass accumulation were more favourable under CCF, especially in Central and Northern Sweden. This resulted in stronger carbon sinks and larger carbon stocks in living biomass compared with RFM. Although much of the carbon sequestration effect was explained by the 20% protected forest area common to all scenarios, CCF further enhanced the accumulation of biomass and product carbon stocks through the harvest of larger logs. Differences between management systems, therefore, reflect both management practices and underlying scenario assumptions.

Most multiple-use indicators also favoured CCF. Scenic beauty and bilberry yields were higher under CCF, while lingonberry and mushroom yields showed only small differences between management systems. Biodiversity responses varied: CCF increased broadleaf volume but did not consistently outperform RFM in species diversity (Shannon index), and deadwood and large-tree volumes were similar across scenarios—largely due to the influence of the assumptions regarding protected forests and retention practices.

Overall, the results indicate that CCF provides a more favourable balance between timber production, carbon sequestration, and several ecological and recreational values, without substantially compromising the long-term timber supply. RFM maintains a more even supply of pulpwood and biofuel, but at the cost of lower carbon stocks, weaker multiple-use values, and a less favourable assortment structure. The mixed scenario (RFM+CCF) generally produced intermediate outcomes, confirming that combining management systems can balance production goals with ecological performance.

Technical appendix – Models, methods, and parameters used in calculations

Growth models

The measurements of the permanent plots of the Swedish National Forest Inventory (NFI) in 2011–2015 (1st measurement) and 2016–2020 (2nd measurement) were used for growth, survival and ingrowth modelling. Only plots fully located within a single stand were used as (Pukkala et al. 2026). Plots that had been cut between the two measurement occasions were not used. These restrictions resulted in 9231 plots. All trees with dbh ≥ 4 cm at the first measurement were used in survival and diameter increment modelling. This resulted in 187,108 tree-level observations, of which 183,211 trees (97.9%) were survivors. The dataset contained 66973 pines, 74814 spruces and 45321 trees of other species. The percentage of survivals was 98.5 for pines, 98.2 for spruce and 96.5 for the other species.

The **diameter increment model** is:

$$\begin{aligned}\widehat{id}_{ij} = \exp\Big(& a_0 + a_1\sqrt{d} + a_2 d + a_3\ln(G + 0.001) + a_4\frac{BALp}{\sqrt{d+1}} + a_5\frac{BALs}{\sqrt{d+1}} + \\ & a_6\frac{BALs+BALo}{\sqrt{d+1}} + a_7\frac{BALp+BALo}{\sqrt{d+1}} + a_8\frac{BAL}{\sqrt{d+1}} + a_9 SI + b_1 d \times Silver + b_2 d \times Downy + \\ & b_3 d \times AspBeech + b_4 d \times Oak + b_5 d \times Contorta + b_6 d \times GreyAlder + \\ & b_7 d \times Rowan + u_j\Big)\end{aligned}$$

where $\widehat{id}_{ij}$ is the 5-year diameter increment of tree i in plot j (cm), G is basal area (m^{2}ha^{-1}), BAL is basal area of larger trees (m^{2}ha^{-1}), SI is site index (m), and *Silver*, *Downy*, *AspBeech*, *Oak*, *Contorta*, *GreyAlder* and *Rowan* are indicator variables for *Betula pendula*, *B. pubescens*, *Populus tremula* or *Fagus sylvatica*, *Quercus robur*, *Pinus contorta* and *Sorbus aucuparia*, respectively, and u_j is the effect of plot j (random plot effect). $BALp$, $BALs$ and $BALo$ mean that the BAL is computed only from Scots pines ($BALp$), spruces ($BALs$) or species that are not Scots pines or spruces ($BALo$). The parameters of the model are in Table A1.

Table A1. Parameters of the diameter increment models.

Parameter	Predictor	Pine	Spruce	Broadleaves
a_0	Intercept	-1.0973	-1.3208	-1.2625
a_1	$\sqrt{d}$	0.6251	0.5055	0.4130
a_2	d	-0.0832	-0.0588	-0.0616
a_3	$\ln(G+0.001)$	-0.3032	-0.2403	-0.1713
a_4	$BALp/\sqrt{(d+1)}$	-	-	-0.0849
a_5	$BALs/\sqrt{(d+1)}$	-	-0.1172	-
a_6	$(BALs+BALo)/\sqrt{(d+1)}$	-	-	-0.1433
a_7	$(BALp+BALo)/\sqrt{(d+1)}$	-	-0.0477	
a_8	$BAL/\sqrt{(d+1)}$	-0.1110	-	-
a_9	SI	0.0629	0.0664	0.0613
b_1	$d \times Silver$	-	-	0.0079
b_2	$d \times Downy$	-	-	-0.0048
b_3	$d \times AspBeech$	-	-	0.0219
b_4	$d \times Oak$	-	-	0.0141
b_5	$d \times Contorta$	-	-	0.0328
b_6	$d \times GreyAlder$	-	-	-0.0108
b_7	$d \times Rowan$	-	-	-0.0295
Sdev[1] of the plot factor (u)		0.39	0.48	0.49

[1] Standard deviation

The **survival model** is as follows:

$$\hat{s} = \frac{1}{1 + \exp\left[-\left(a_0 + a_1 \ln d + a_2\sqrt{d} + a_3 d + a_4\frac{BALp}{\sqrt{d+1}} + a_5\frac{BALs + BALo}{\sqrt{d+1}} + a_6\frac{BALs}{\sqrt{d+1}} + a_7\frac{BALp + BALo}{\sqrt{d+1}} + a_8\frac{BALo}{\sqrt{d+1}} + a_9 SI\right)\right]}$$

where $\hat{s}$ is the probability that the tree will survive for five years (the other symbols are as before). Table A2 shows the parameters of the survival model.

Table A2. Parameters of survival models.

Parameter	Predictor	Pine	Spruce	Broadleaves
a_0	Intercept	4.6148	7.7606	4.6433
a_1	ln(*d*)	-	-1.2860	-
a_2	√*d*			-0.5351
a_3	*d*	-0.0200	-	-
a_4	*BALp*/√(d+1)	-0.2179	-	-0.0845
a_5	(*BALs*+*BALo*)/√(*d*+1)	-0.3714	-	-
a_6	*BALs*/√(*d*+1)	-	-0.1752	-0.1191
a_7	(*BALp*+*BALo*)/√(*d*+1)	-	-0.0973	
a_8	*BALo*/√(d+1)	-	-	-0.1698
a_9	*SI*	0.0374	0.0225	0.0599

The **ingrowth model** is a zero-inflated negative binomial model that consists of two sub-models: one for the count (the number of ingrowth trees within a circular plot of 3.5-meter radius) and one for the "extra zeroes". The extra zero model predicts the probability that the plot has no ingrowth trees. The count (y) and extra zero (p_{Zero}) models are as follows:

Count model:

$$\hat{y} = \exp\left(a_0 + a_1\sqrt{G} + a_2\sqrt{G_\mathrm{p}} + a_3\sqrt{G_s} + a_4\sqrt{G_\mathrm{o}} + a_5 D + a_6 \ln D + a_7 SI + a_8 L + a_9 A\right)$$

Extra zero model:

$$\hat{p}_\mathrm{Zero} = \frac{1}{1+\exp\{-(a_0+a_1\sqrt{G}+a_2\sqrt{G_\mathrm{p}}+a_3\sqrt{G_\mathrm{s}}+a_4 D+a_5\ln D+a_6 SI+a_7 L)\}}$$

where $\hat{y}$ is the number of ingrowth trees (in a 38.5-m^2 plot in five years), $\hat{p}_\mathrm{Zero}$ is the extra zero-probability, G is the stand basal area (m^{2}ha^{-1}), G_p is the basal area of pines (m^{2}ha^{-1}), G_s is the basal area of spruces (m^{2}ha^{-1}), G_o is the basal area of other species (m^{2}ha^{-1}), D is the basal-area-weighted mean diameter (cm), SI is the site index (m), L is latitude (degrees) and A is altitude (m). The ingrowth prediction is obtained as follows:

$$Ingrowth = \hat{y}(1-\hat{p}_\mathrm{Zero})$$

where *Ingrowth* is the number of ingrowth trees in a 38.5-m^2 plot in 5 years. The prediction must be multiplied by 259.84 to obtain a per-hectare prediction. The parameters of the two sub-models are in Table A3.

Table A3. Parameters of the ingrowth models.

Parameter	Predictor	Pine	Spruce	Broadleaves
		Extra zero model		
a_0	Intercept	-5.6572	-14.4480	0.0590
a_1	$\sqrt{G}$	0.4010	-0.4324	-2.0396
a_2	$\sqrt{G_p}$	-0.2274	0.1916	1.3548
a_3	$\sqrt{G_s}$	-	0.7958	-
a_4	D	-0.0727	-0.1926	-0.0735
a_5	ln$D$	2.0350	4.8662	1.7217
a_6	SI	0.0581	0.1001	-0.0835
a_7	L	-	-0.2297	-
		Count model		
a_0	Intercept	6.9334	0.3656	4.3244
a_1	$\sqrt{G}$	-0.8340	-0.7303	-0.9051
a_2	$\sqrt{G_p}$	0.3599	0.2506	0.2241
a_3	$\sqrt{G_s}$	-	0.6615	-
a_4	$\sqrt{G_o}$	-	0.1983	0.5354
a_5	D	0.0669	0.0727	0.0666
a_6	ln$D$	-0.9069	-1.5686	-1.7728
a_7	SI	-	0.0991	-
a_8	L	-0.0613	-	-
a_9	A	-0.0021	-	-
	Overdispersion	1.9093	0.5428	0.3435

The last model for simulating the stand dynamics is for the **mean diameter of ingrowth trees**:

$$D_{\text{In}} = a_0 + a_1\sqrt{G} + a_2\ln SI$$

where D_{In} is the mean diameter of the ingrowth trees (mm), G is the stand basal area (m^2ha^{-1}) and SI is the site index (m). The parameters of this model are in Table A4.

Table A4. Parameters of the models for the mean diameter of ingrowth trees (equation 10). The mean diameter of ingrowth trees is in millimeters.

Parameter	Predictor	Pine	Spruce	Broadleaves
a_0	Intercept	32.1464	30.4700	29.1592
a_1	$\sqrt{G}$	-1.9888	-1.5230	-0.9586
a_2	lnSI	7.7569	7.9090	7.1688

Volume

The total and assortment volumes of the tree stems are calculated with the taper models of

Laasasenaho (1982). Each stem was divided into a maximum of four assortments of merchantable timber: large sawlog, sawlog, pulpwood log, and fuelwood log. The definitions of the assortments are in Table A5.

Table A5. Assortments of merchantable timber. The last column (sawn wood and plywood yield) affects the product carbon stores and substitution effects.

Species	Assortment	Min top diameter, cm	Min log length, m	Roadside price, SEK/m3	Proportion of sawn wood + plywood
Pine	Large sawlog	28	4.5	1050	0.6
Pine	Sawlog	15	4.5	850	0.4
Pine	Pulpwood	5	4	600	0
Pine	Fuelwood	3	2	490	0
Spruce	Large sawlog	28	4.5	950	0.65
Spruce	Sawlog	15	4.5	850	0.45
Spruce	Pulpwood	5	4	600	0
Spruce	Fuelwood	3	2	490	0
Birch	Large sawlog	28	4.0	1100	0.4
Birch	Sawlog	18	4.0	900	0.25
Birch	Pulpwood	5	4	600	0
Birch	Fuelwood	3	2	490	0
Other	Large sawlog	28	4.0	800	small
Other	Sawlog	18	4.0	600	small
Other	Pulpwood	5	4	450	0
Other	Fuelwood	3	2	400	0

Economic parameters

The net income of timber sales was calculated as the difference between the roadside value of harvested trees minus harvesting costs. Time consumption functions of Rummukainen et al. (1995) were used to calculate the time consumption of the harvester and forwarder (assuming 20 meters between extraction roads and 200-meter forwarding distance. These times were multiplied by the hourly costs of the machines, which were 1400 SEK/hour for the harvester and 1100 SEK/hour for the forwarder.

The costs of silvicultural operations were:

- Scarification: 3216 SEK/a
- Planting: 6396 SEK/ha
- Pre-commercial thinning: 3958 SEK/ha
- Cleaning of undergrowth: 1846 SEK/ha

Biomass

The models of Repola et al. (2007) were used to calculate the biomass (dry mass) of tree stems, stumps, roots, branches, and foliage. Since there is no model for the fine roots and root tips, their amount was predicted from foliage biomass using the parameters shown in Table A8 (rightmost column).

Carbon stocks and carbon balance

The dynamics of three carbon pools were simulated: (1) living tree biomass, (2) dead organic material (DOM), and (3) harvested wood products (HWP). All pools were initialized (the pool size at the beginning of the simulation was calculated), separately for each inventory plot. Then, the inputs and outputs of each were simulated. During simulation, the pool sizes were expressed as tons of dry matter per hectare. To obtain carbon pools, the pool sizes were multiplied by the carbon content of the biomass (0.5).

The biomass pool was initialized using the measured tree data of the inventory plots and the biomass models of Repola et al. (2007). Inputs to the biomass pool consisted of the growth of tree biomass (including the biomass of ingrowth trees). The outputs consisted of mortality and cuttings.

The DOM pool of each plot was initialized with the models of Pukkala (2020). The inputs to the DOM pool consisted of dead trees, harvest residual, and the annual litter yield of the living trees. The carbon output from the DOM pool was calculated using the Yasso15 decomposition model (reference). Since the Yasso model simulates the dynamics of different chemical and size fractions of DOM, the DOM pool was initialized separately for 15 different DOM components (three size classes × five solubility classes). The initialization models and their parameters are in Tables A6, A7 and A8.

Table A6. Parameters of the models for the dry matter pools of undimensional DOM. The model is:
Pool = exp(b_0+ $b_1\sqrt{G}$+ b_2 G+ b_3/(yrs+1)+$b_4\sqrt{H}$+ $b_5$ln(TS/1000)+b_6Mesic+b_7SubXeric+b_8Xeric). The pool size is in t/ha.

Parameter	Predictor	Acid-soluble	Water-soluble	Ethanol-soluble	Non-soluble	Humus
b_0	Intercept	1.977472	−0.321687	−0.512114	3.771108	3.319
b_1	$\sqrt{G}$	−0.011602	0.016291	0.098156	−0.300864	−0.054140
b_2	*G*	0.01724	0.015484	0.010672	0.034895	0.004883
b_3	1/(*yrs*+1)	2.070936	2.121223	2.373142	0.879274	0.05459
b_4	$\sqrt{H}$	0.237232	0.227348	0.217417	0.291089	0.06281
b_5	ln(*TS*/1000)	−0.835086	−0.849416	−0.922936	−0.271503	0.6035
b_6	*Mesic*	−0.038614	−0.040012	−0.050359	−0.056773	−0.119900
b_7	*SubXeric*	−0.117201	−0.118923	−0.145180	−0.158373	−0.249000
b_8	*Xeric*	−0.175446	−0.174873	−0.191118	−0.267825	−0.457600

TS = temperature sum (d.d.), *G* = basal area (m^2ha^{-1}), *H* = basal-area-weighted mean height (m) *Mesic, SubXeric* and *Xeric* are indicator variables for site fertility classes.
yrs = *H*/(*TS*/1000)

Table A7. Parameters of the models for the dry matter pools of stumps and stems of small trees (0–10 cm in dbh). The model is: Pool = exp(b_0+ $b_1\sqrt{G}$+ b_2G+ b_3/(yrs+1)+$b_4\sqrt{H}$+ $b_5$ln(TS/1000)+ b_6Mesic+b_7SubXeric+b_8Xeric). The pool size is in t/ha.

Parameter	Predictor	Acid-soluble	Water-soluble	Ethanol-soluble	Non-soluble	Humus
b_0	Intercept	−0.257503	−2.552059	−2.731000	1.261003	0.5159
b_1	$\sqrt{G}$	−0.027848	−0.028145	−0.007461	−0.020269	0.001219
b_2	*G*	0.000507	0.000496	0.000065	0.001058	−0.000137
b_3	1/(*yrs*+1)	0.376131	0.386856	−0.045360	−0.011542	−0.011360
b_4	$\sqrt{H}$	0.05729	0.05865	−0.003821	0.011205	−0.001622
b_5	ln(*TS*/1000)	−1.597582	−1.594693	−1.749000	−1.350845	0.3568
b_6	*Mesic*	−0.109293	−0.108227	−0.146000	−0.142388	−0.192600
b_7	*SubXeric*	−0.315448	−0.314112	−0.351600	−0.357358	−0.391700
b_8	*Xeric*	−0.553587	−0.552355	−0.578900	−0.595878	−0.596500

TS = temperature sum (d.d.), *G* = basal area (m^2ha^{-1}), *H* = basal-area-weighted mean height (m) *Mesic, SubXeric* and *Xeric* are indicator variables for site fertility classes.
yrs = *H*/(*TS*/1000)

Table A8. Parameters of the models for the dry matter pools of stumps and stems of large trees (>10 cm in dbh). The model is: $Pool = \exp(b_0 + b_1\sqrt{G} + b_2G + b_3/(yrs+1) + b_4\sqrt{H} + b_5\ln(TS/1000) + b_6Mesic + b_7SubXeric + b_8Xeric)$. *The pool size is in t/ha.*

Parameter	Predictor	Acid-soluble	Water-soluble	Ethanol-soluble	Non-soluble	Humus
b_0	Intercept	1.5030721	−0.7798507	−1.2499816	2.8419507	0.2241904
b_1	$\sqrt{G}$	−0.7594748	−0.765483	−0.186562	−0.2614734	−0.0373336
b_2	G	0.0767962	0.0774085	0.0184351	0.0249927	0.0032109
b_3	$1/(yrs+1)$	0.5409353	0.546307	−0.3345018	−0.3035379	−0.1662712
b_4	$\sqrt{H}$	0.5226466	0.5266622	0.076254	0.1354002	0.0097665
b_5	$\ln(TS/1000)$	−0.3650836	−0.3687357	0.4087603	0.7356049	1.1606087
b_6	*Mesic*	−0.2746126	−0.2735458	−0.3162969	−0.359797	−0.3877656
b_7	*SubXeric*	−0.2100956	−0.20686	−0.2707342	−0.441509	−0.5297087
b_8	*Xeric*	−0.3374827	−0.3330458	−0.4837796	−0.6871823	−0.837371

TS = temperature sum (d.d.), G = basal area (m^2ha^{-1}), H = basal-area-weighted mean height (m) *Mesic, SubXeric* and *Xeric* are indicator variables for site fertility classes. $yrs = H/(TS/1000)$

The annual litter inputs to the DOM pools were based on the biomass turnover rates (Table 8). The turnover rate is the proportion of biomass that is shed annually as litter. The last column of Table 8 is used to estimate the biomass of fine roots. The fine root biomass is the ratio shown in Table A9 multiplied by foliage biomass.

Table A9. Turnover rates for different tree species and biomass components:

		Turnover rate		
Species	Foliage	Branches and roots	Fine roots	Fine-root/foliage biomass ratio
Pine	0.3	0.0125	0.811	0.67
Spruce	0.2	0.0125	0.868	0.25
Broadleaves	1	0.0135	1	0.67

The initial sizes of the HWP pools were calculated with the models of Pukkala (2020), separately for each inventory plot and the following product categories: sawn wood (including also plywood and veneer), mechanical mass products, chemical mass products and biofuel. The models and their parameters are in Table A10. The initial pools express the remaining dry mass of the products prepared from trees harvested earlier from the stand.

Table A10. Parameters of the models for the initial dry matter pools of wood-based products. The model is: $PoolSize = exp(b_0 + b_1G + b_2/yrs + b_3H + b_4ln(TS/1000) + b_5Mesic + b_6SubXeric + b_7Xeric)$*. The unit of pool size is t/ha.*

Parameter	Predictor	Sawn wood	Mechanical mass	Chemical mass	Bioefuel
b_0	Intercept	4.047	−0.851205	−0.103326	−1.191293
b_1	*G*	−0.026740	−0.076262	−0.096778	−0.085597
b_2	1/*yrs*	0.07422	0.805201	0.562171	0.748571
b_3	H	0.01022	0.091064	0.085136	0.093705
b_4	ln(*TS*/1000)	1.401	−0.168897	1.09273	0.42194
b_5	*Mesic*	−0.209700	−0.382614	0.012586	−0.208939
b_6	*SubXeric*	−0.286000	−1.112986	0.162944	−0.291559
b_7	*Xeric*	−0.613300	−1.536224	−0.283060	−0.710722

TS = temperature sum (d.d.), *G* = basal area (m^2ha^{-1}), *H* = basal-area-weighted mean height (m) *Mesic, SubXeric* and *Xeric* are indicator variables for site fertility classes.
yrs = *H*/(*TS*/1000)

Inputs of the HWP pool consisted of harvested trees (those parts of the trees that were transported away from the forest). Each timber assortment was divided into several product categories (sawn wood, plywood, particle board, pulp and paper, biofuel, etc). The permanence of carbon in wood products was based on product half-lives (the number of years during which 50% of the product is discarded). The half-life times were converted into annual disposal rates (proportion of dry mass discarded annually, *k* in Table A11).

Table A11. Annual disposal rates and substitution factors for wood products

Product	Annual disposal rate (*k*)	Substitution factors			
		When manufactured		At the end of life	
		2020	2050	2020	2050
Sawn wood	0.0198	0.93	0.34	0.22	0.09
Plywood, veneer	0.0198	0.51	0.31	0.27	0.1
Poles	0.0198	0.93	0.34	0.22	0.09
Particleboard	0.05	0.36	0.13	0.41	0.15
Mech. mass products	0.25	0.06	0.1	0.26	0.09
Chem. mass products	0.25	0.1	0.07	0.26	0.09
Biofuel CHP[1]	0.6931	0.57	0.11	0	0
Biofuel Mill[2]	0.6931	0	0	0	0

[1] Central heating plant
[2] Mill energy

Table A11 also includes the substitution factors (reduced fossil emissions due to the use of wood). It was assumed that the substitution factors decrease with time because of the gradual decarbonization of alternative energy sources and materials. The substitution factors are based on the study of Hurmerinta et al. (2020). When the product is discarded, it can be used for another purpose (usually biofuel). Therefore, another substitution factor is used for the products when they are discarded (‘At the end of life’ in Table A11).

Multiple-use indicators

The mean annual yields of **bilberry**, **lingonberry** and commercial **mushrooms** of *Boletus* sp. *Lactarius* sp. are calculated with the models of Kurttila et al. (2018). Most of the empirical data behind the model has been collected in the eastern part of Central Finland. Therefore, the models may not be reliable for Sweden, especially southern and northern Sweden.

$$Bilberry = \exp(1.723 + 0.376\sqrt{D} - 0.543P_{\text{Birch}} - 0.288P_{\text{Spruce}} - 0.083G/\ln(D+1) + 0.000519D \times G$$
$$- 0.000263G^{2} - 1.542HerbRich - 0.626SubXeric - 1.511Xeric)$$

$$Lingonberry = \exp(1.323 + 0.073\ln(D+1) + 0.166P_{\text{Pine}} - 0.072P_{\text{Spruce}} - 0.040 \times G/\ln(D+2) + 0.509Mesic$$
$$+ 1.601(SubXeric \text{ or } Xeric))$$

$$Mushrooms = \exp(0.969 + 1.718\ln(Gro + 0.001) - 0.144Gro)$$

where *Bilberry* and *Lingonberry* are, respectively, the yield of bilberry and lingonberry in the stand ($\text{kg ha}^{-1}\text{a}^{-1}$); D is the mean breast height diameter (cm); and P_{Birch}, P_{Spruce}, and P_{Pine} are the proportions of broadleaves, spruce, and pine of the stand's basal area. *Gro* is the five-year stand volume increment (m^3ha^{-1}) predicted by Monsu forest planning software. The models predict that both bilberry and cowberry yields are the highest on sub-xeric sites and in pine-dominated stands. A low stand density is associated with high lingonberry yields, but low bilberry yields.

The **scenic beauty score** describes the perception of people who are walking. It is based on ratings of people for different types of forests. The rating used was from 0 (extremely bad) to 10 (extremely good). The model is

$$ScenicBeauty = 4.471 + 0.0654D - 0.0001745N + 0.006439V_{\text{Pine}}S + 0.005733V_{\text{BirchAspen}}S$$

where D is the mean tree diameter, weighted by basal area (cm), N is the number of trees per hectare, V_{Pine} is the volume of pines (m^3ha^{-1}), $V_{\text{BirchAspen}}$ is the volume of birch and aspen (m^3ha^{-1}), and S is an indicator variable that is 1 if dominant height is > 10 m and 0 otherwise.

Biodiversity indicators

The **volume of dead trees**, when used as a biodiversity indicator, is calculated by simulating the stem decomposition of each dead tree. When a tree dies, it is given an annual decomposition rate, which depends on species, diameter (dbh), and temperature sum (Fig. A1). For example, birch stems decompose faster than pines and spruces, and small trees decompose faster than large ones.

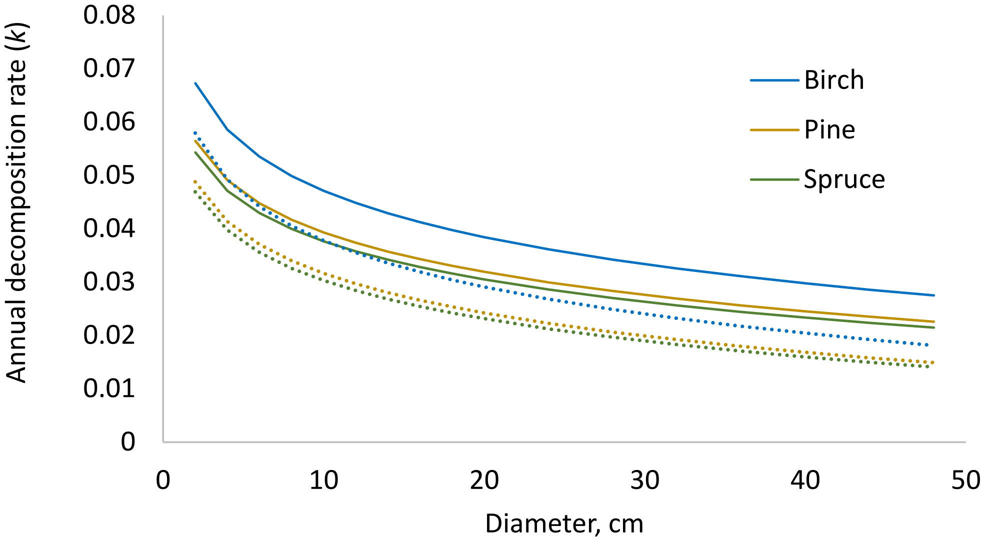


Figure A1. Dependence of the decomposition rate of the stems of dead trees on tree species, diameter, and temperature sum. Solid lines are for the temperature sum 1400 d.d., and dotted lines are for 900 d.d.

When a certain percentage of the biomass has decomposed, the decomposition class of the stem changes (Fig. A2). There are five different classes (stages of decomposition). When the remaining biomass is lower than the lower limit of Stage 5, the stem is classified as detritus and is no longer included in deadwood volume. By using this method, the volume of dead trees can be calculated for different species, diameter classes, and stages of decomposition.

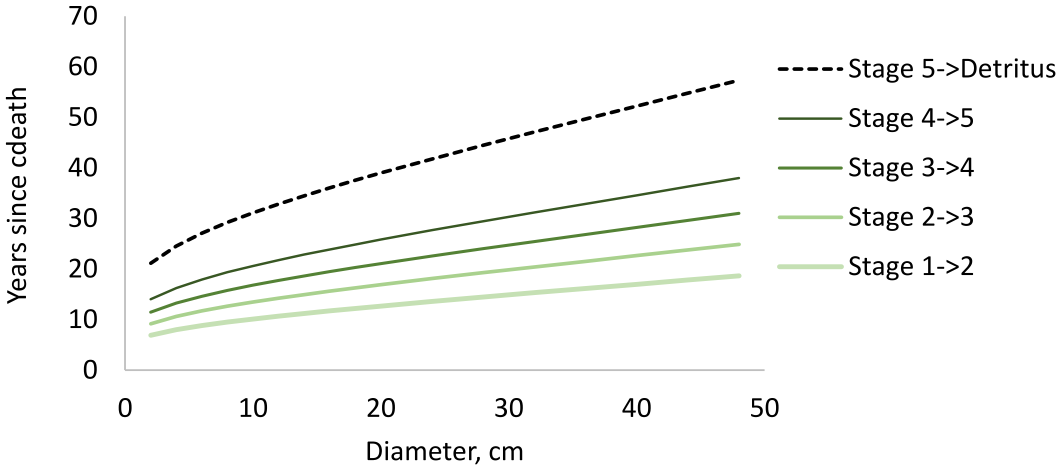


Figure A2. Yeas at which the decomposition class of a conifer stem changes (when the temperature sum 1200 d.d.).

Because the inventory data of the NFI plot did not include sufficient data about dead trees, the initial number of dead trees (by species and stage of decomposition) was predicted with a model set that is based on long-term simulations with the Monsu software. Each of the initial dead trees was given an annual decomposition rate, which was used to simulate its further decomposition.

The **volume of large trees** includes trees whose dbh is larger than a dbh limit. The limit depends on site fertility and temperature sum (Fig. A3). Figure A3 shows that the limit is smaller for poor sites. The limit also decreases toward the north (Pukkala 2022). The limiting diameter is calculated as:

Dbh limit (cm) = $a \times 30 + ((TS\text{-}700)/1000)\times 10$

where TS is the temperature sum (d.d.) and a is a parameter that depends on site fertility (herb-rich or better 1.0, Mesic 0.9, sub-xeric 0.8, xeric or poorer 0.7).

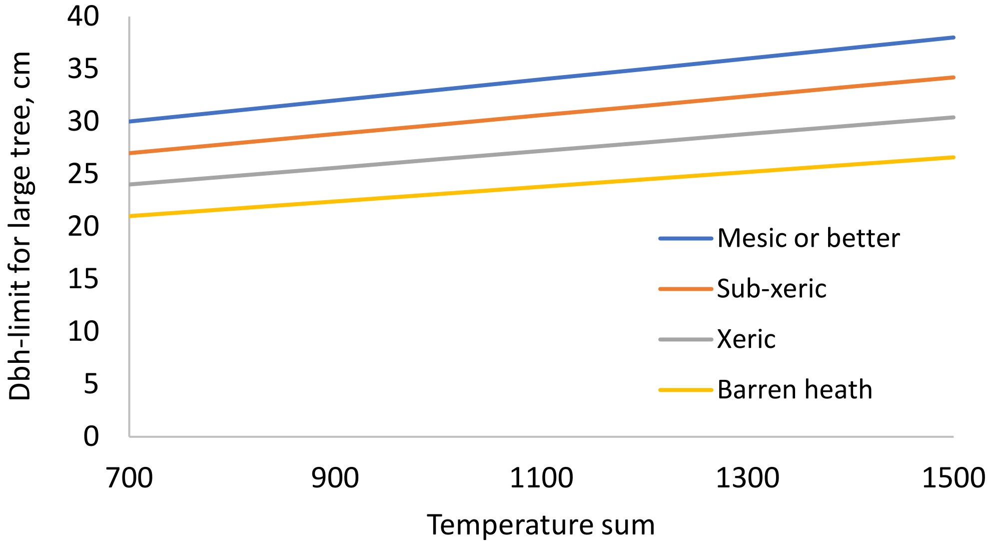


Figure A3. Dbh limit for a large tree.

The **broadleaf volume** is the stem volume of all broad-leaved tree species.

The **diversity of tree species** (Shannon index) is calculated first for every simulation unit (sample plot), after which the average over all simulation units is calculated. The Shannon index is calculated as:

$$S = -\sum p_i \ln(p_i)$$

where p_i is the proportion of species i of the stand basal area.

CCF management guidelines used in simulation

The first commercial thinning of a young stand is simulated as a thinning from below, in the same way in both RFM and CCF. The prior- and post-thinning basal area recommendations indicate the basal area that should be removed. Half of the removed basal area is taken by using the same thinning rate in all diameter classes. The other half is obtained by removing the smallest trees until the remaining basal area is at the recommended post-thinning level (Äijälä et al. 2018).

In all other cutting, the management guidelines of Pukkala (2022) are used. The guidelines are based on a large number of optimizations where the net present value has been maximized at different discount rates. The guidelines consist of three models:

1. Probability that cutting the stand now is the optimal decision
2. Probability that the optimal cutting is thinning (instead of final felling)
3. Thinning intensity in different diameter classes

When simulating CCF management, the cutting type was always thinning, which means that model 2 was not used.

The model for the probability that cutting the stand is the optimal decision is:

$$p_{\mathrm{cut}} = \frac{1}{1+\exp[-(X)]}$$

where

$$X = 7.8088 - 0.7444\mathrm{n}G_{\min} + 1.9687\ln D\ln G - 0.2500\sqrt{D}\sqrt{G} + 0.001371TS\ln R - 2.8760\ln TS - 0.6799H - 0.24474M - 0.0585S \tag{12}$$

The explanatory variables were minimum allowed post-thinning basal area ($G_{\min}$, m^{2}ha^{-1}), basal-area-weighted mean diameter (D, cm), stand basal area (G, m^{2}ha^{-1}), temperature sum (TS, d.d.), discount rate (R, %) and three indicator variables for site fertility categories: H = herb-rich or better, M = mesic, S = sub-xeric. All indicator variables are zero if the site fertility class is xeric or poorer.

Cutting was simulated if the $p_{\mathrm{Cut}} > 0.5$ (probability that cutting the stand now is the optimal decision was 0.5 or more). The minimum allowed post-cutting basal area was 12, 11, 10, 9, 8 or 7 m^{2}ha^{-1} for mesotrophic, herb-rich, mesic, sub-xeric, xeric, and heath sites, respectively. These values do not mean that the stand was thinned to these post-cutting basal areas. The values were only used as a predictor in the cutting probability model ($G_{\min}$). Figure 4 shows examples of how the probability of cutting depends on basal area, mean tree diameter, temperature sum and discount rate (on mesic site). Increasing basal area, tree diameter, and discount rate increases the maturity for cutting, and increasing temperature sum decreases it.

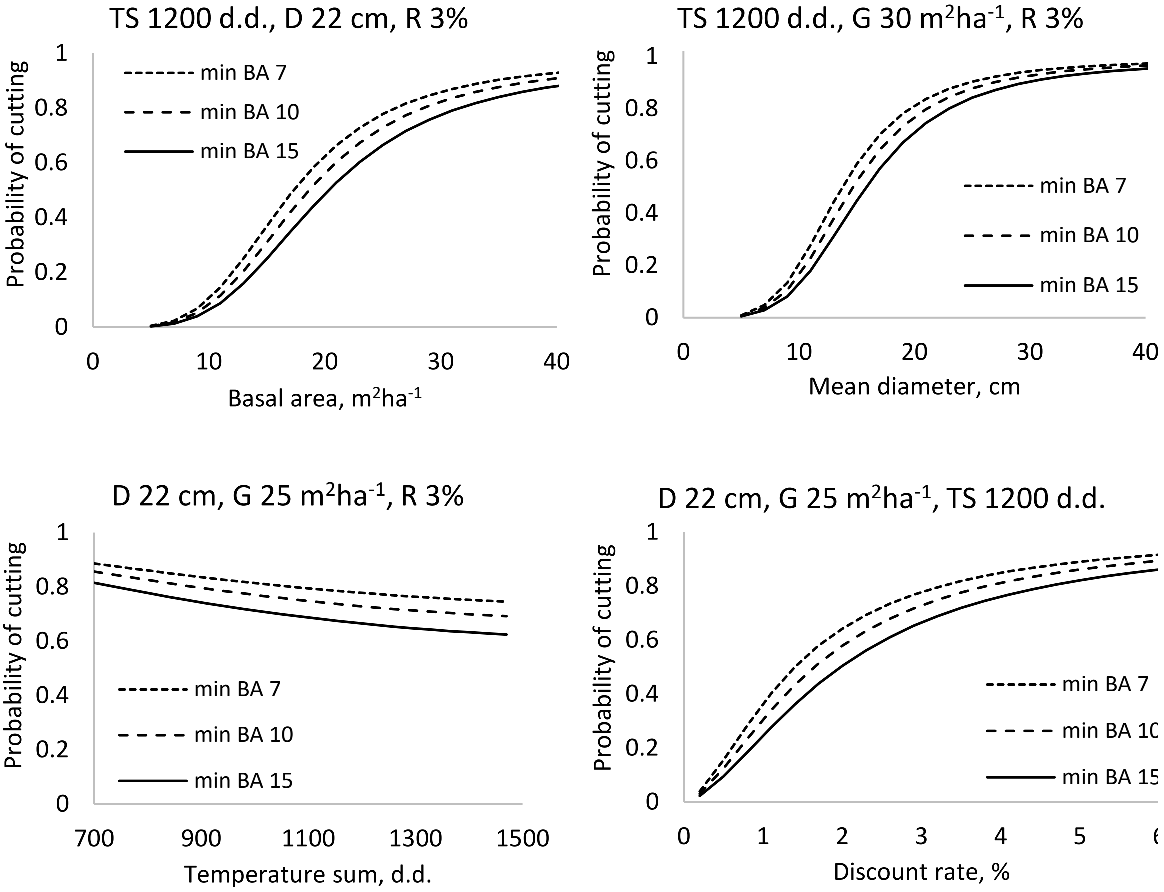


Figure A4. The probability that harvesting is the optimal decision in a mesic site. TS is the temperature sum, D is the mean diameter, G is the basal area, R is the discount rate, and min BA is the lowest allowed post-thinning basal area (m²ha⁻¹).

The thinning intensity (proportion of trees removed) in different diameter classes is calculated with the following logistic formula:

$$p_{\text{remove}}(d) = \frac{1}{1+\exp[a_1(a_2-d)]}$$

where $p_{\text{remove}}(d)$ is the proportion of trees removed when the diameter is d cm, and a_1 and a_2 are parameters. Parameter a_2 is the dbh at which the thinning intensity is 50%. Parameter a_1 shows the type of thinning. If $a_1 > 0$, the thinning is from above, i.e., the thinning intensity increases towards larger trees. If $a_1 = 0$, the thinning intensity is the same for all diameter classes, and $a_1<0$ indicates thinning from below.

The management guidelines for CCF include models for both parameters of the logistic thinning intensity curve:

$a_1 = -30.354 + 17.231 \sqrt{D} - 1.503\, D$

$$a_2 = \exp(0.4006 + 0.0594\ln G_{min} + 0.7830\ln D - 0.1173\ln G + 0.0989\ln TS - 0.1071\ln R + 0.0408H + 0.0471M + 0.0333S)$$

Figure A5 shows examples of partial cuttings when the CCF guidelines are applied to two different diameter distributions. The optimal cutting is almost always thinning from above.

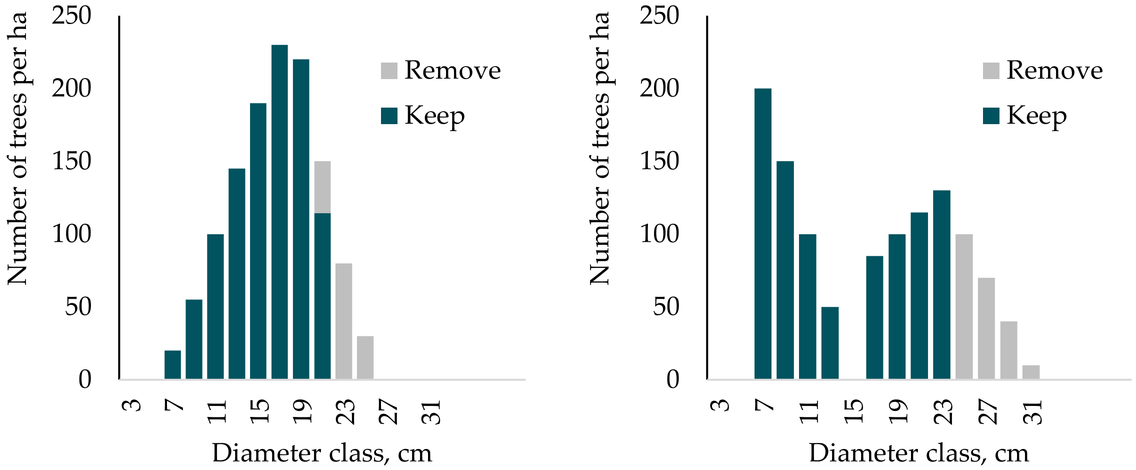


Figure A5. Prior- and post-thinning number of trees in 2-cm diameter classes when thinning is simulated according to the CCF guidelines (TS 1200 d.d., the discount rate is 3%, the lowest allowable post-thinning basal area is 9 $m^2ha^{-1,}$ and the site is mesic).

Several alternative CCF management schedules were simulated for each simulation unit (NFI plot). Alternatives were produced by applying the guidelines with different discount rates, and prohibiting cutting during the first, second, etc., time period of the simulation. The simulation consisted of five 5-year periods, followed by five 10-year periods (75 years total).

Conversions

Part of the models or parameters used in the simulation require information on the temperature sum or site fertility. These variables were not available for the Swedish NFI plots. The available site variables were site index, latitude, and altitude. The temperature sum (d.d.) was calculated from latitude (degrees) and altitude (meters) as follows:

$$TS = 4500 - 50 \times Latitude - 0.6 \times Altitude$$

Some parameters, such as the planted tree species and the amount of regeneration of non-planted species in clear-cut areas, depend on the fertility class. The fertility class of each plot was deducted based on the temperature sum and site index using the relationships visualized in Figure A6. It is assumed that trees of a certain fertility class get shorter towards the north.

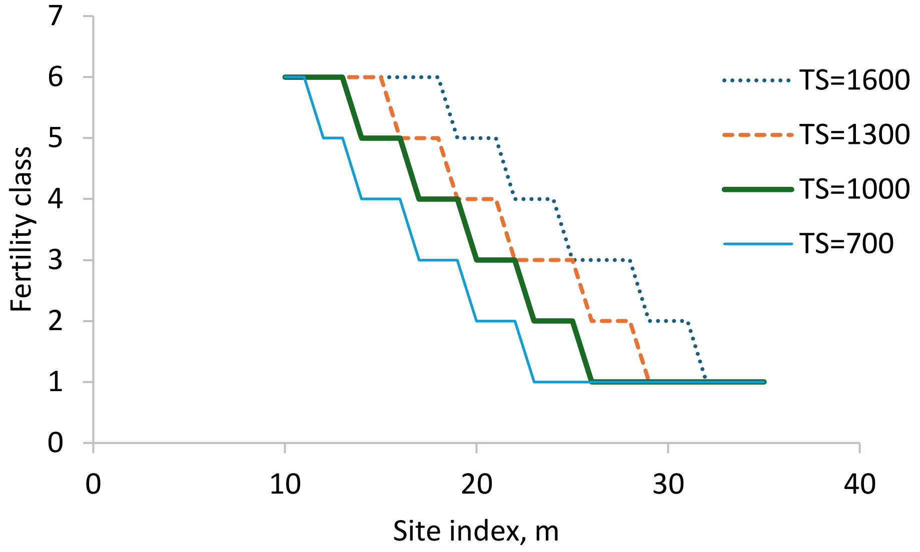


Figure A6. Dependence of site type (fertility class) on site index and temperature sum. Fertility class 1 = mesotrophic site, 2 = herb-rich, 3 = mesic ("bilberry site"), 4 = sub-xeric ("lingonberry site"), 5 = xeric site ("heather site") and 6 = barren heath ("lichen site").

References

Hurmekoski E, Kunttu J, Heinonen T, Pukkala T, Peltola H (2023) Does expanding wood use in construction and textile markets contribute to climate change mitigation? Renewable and Sustainable Energy Reviews, Volume 174, 113152,. https://doi.org/10.1016/j.rser.2023.113152.

Kurttila M, Pukkala T, Miina J (2018) Synergies and trade-offs in the production of NWFPs predicted in boreal forests. Forests 9: 1–15 https://doi.org/10.3390/f9070417

Pukkala T, Kellomäki S, Mustonen E (1988) Prediction of the amenity of a tree stand. Scand J For Res 3: 533–544

Pukkala T (2020) Calculating the additional carbon sequestration of Finnish forestry. J Sust For https://doi.org/10.1080/10549811.2020.1792935. Appendix table 1

Pukkala T (2021) Measuring the social performance of forest management. Journal of Forest Research 32: 1803–1818 https://doi.org/10.1007/s11676-021-01321-z

Pukkala T (2022) Assessing the externalities of timber production. Forest Policy and Economics 135 (2022), 102646. https://doi.org/10.1016/j.forpol.2021.102646

Pukkala T, Löf M, Snäll T (2025) Continuous cover forestry compatible models for the dynamics of forest stands in Sweden. Manuscript.

Laasasenaho J (1982) Taper curve and volume functions for pine, spruce and birch. Communicationes Instituti Forestalis Fenniae 108: 1–74

Repola J, Ojansuu R, Kukkola M (2007) Biomass functions for Scots pine, Norway spruce and birch in Finland (Vol. 53). Working Papers of the Finnish Forest Research

Rummukainen A, Alanne H, Mikkonen E (1995) Wood procurement in the pressure of change-resource evaluation model till year 2010. Acta Forestalia Fennica 248: 1–98

Swedish Environmental
Research Institute

STOCKHOLM
Box 21060, 100 31 Stockholm

GOTHENBURG
Box 53021, 400 14 Gothenburg

MALMÖ
Nordenskiöldsgatan 24
211 19 Malmö

KRISTINEBERG
(Center for Marine Research and Innovation)
Kristineberg 566
451 78 Fiskebäckskil

SKELLEFTEÅ
Kanalgatan 59
931 32 Skellefteå

BEJING, CHINA
Room 612A
InterChina Commercial Building No.33
Dengshikou Dajie
Dongcheng District
Beijing 100006
China

This report has been reviewed and approved in accordance with IVL's audit and approval management system.