FORWARD PROJECTIONS

SWEDEN

SUPERB
Upscaling Forest Restoration

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EXECUTIVE SUMMARY

The Swedish demo area is located entirely in the Vindelälven-Juhttátahkka UNESCO Biosphere Reserve, covering a vast 1.3 million hectare river catchment from the alpine regions of the Scandinavian Mountain Range bordering Norway to the coast of the Gulf of Bothnia. The forests within the Biosphere Reserve are naturally dominated by native conifers, primarily *Pinus sylvestris* (Scots pine) and *Picea abies* (Norway spruce), along with deciduous trees such as *Betula pendula*, *Betula pubescens*, *Populus tremula*, *Salix caprea*, *Sorbus aucuparia* and *Prunus padus.* Different restoration actions are performed in the Swedish demo area. In Ume Älvdal, Norway spruces are removed to create large areas of deciduous dominated forest. In Ecopark Skatan, improvements are made for connectivity and reindeer herding.

This Swedish projection report is part of the deliverable D6.5 on projected ecosystem data. The forest development under varying restoration scenarios is projected for the upcoming 30-years, until 2055, using the EFISCEN-Space model.

Four scenarios are simulated with the EFISCEN-Space model, a business as usual scenario (BAU) where the forest development under current management is simulated and three alternative scenarios under which 5 management regimes are used in different shares on the forest. The first alternative scenario is a dogma shift scenario, the second is a polarization scenario and the third alternative scenario focuses on biomass production and not at all on nature values.

The model projections showed that none of the alternative scenarios were able to maintain the harvest levels of the BAU scenario, however the species composition, structural composition and increment increased in the alternative scenarios. Unmanaged forest lead in these stands to a larger growing stock and thus carbon storage, however, for creating a more diverse and resilient forest interventions like thinnings and planting are needed.

DEMO INFORMATION

The Swedish demo area is located entirely in the Vindelälven-Juhttátahkka UNESCO Biosphere Reserve, covering a vast 1.3 million hectare river catchment from the alpine regions of the Scandinavian Mountain Range bordering Norway to the coast of the Gulf of Bothnia. The forests within the Biosphere Reserve are naturally dominated by native conifers, primarily *Pinus sylvestris* (Scots pine) and *Picea abies* (Norway spruce), along with deciduous trees such as *Betula pendula*, *Betula pubescens*, *Populus tremula*, *Salix caprea*, *Sorbus aucuparia* and *Prunus padus* (Figure 1). Deciduous-dominated forests occur naturally as succession phases after forest fires, in forest margins, river deltas, and along the coast. Fire is a natural large-scale disturbance driving forest dynamics, especially in dry, pine-dominated areas, whereas forest dynamics in mesic and wet areas are mostly driven by more small-scale disturbances. Nowadays, there are several stressors to the forest ecosystems in the Biosphere Reserve; (1) the dominating silviculture scheme that has been adopted over the last 60-70 years is primarily based on clearcutting, planting, sawing and repeated thinnings, (2) the hampering and loss of natural disturbance such as forest fires, regular flooding and extensive grazing by cattle, sheep. These stressors have led to a reduction of forest structure (e.g., dead wood and old growth trees), reduced variation in species composition, overrepresentation of coniferous species and reduced landscape connectivity for both biodiversity and reindeer grazing and migration. Moreover, the effects of climate change induced the risk of severe drought, outbreaks of pests such bark beetles and the occurrence of invasive tree and plant species.

Figure 1. The initial state of the forest in the Swedish demo area..

The restoration measures are conducted on two main landscapes, Ume Älvdal and Ecopark Skatan, that represent different forest types and restoration activities. In Ume Älvdal, restoration aims to create good habitat for the umbrella species *Dendrocopos leucotos* (white-backed woodpecker) and other species that favor large areas of old deciduous dominated forests with high amount of dead wood. As this type of forests naturally occurs between early successional stage after large-scale disturbance (e.g., fire or flooding) and later successional stages where the forest is dominated by Norway spruces, the restoration activities focus on "speeding-up" succession by increasing amount of dead wood and diameter growth, but also on "slowing down" succession by removing Norway spruces. In contrast to Ume Älvdal, the restoration actions in Ecopark Skatan focus on increasing nature conservation values of Scots pine dominated and deciduous dominated forests through recreating and reestablishing typical forest structures that could also improve landscape function and connectivity for reindeer herding.

MODEL DESCRIPTION

EFISCEN-Space model

EFISCEN-Space is an empirical European forest model that simulates development of forest resources under varying scenarios of forest management and climate change. It keeps track of the development of the diameter distribution of 20 tree species (groups) for individual plot locations (Schelhaas et al., 2022). The diameter distribution changes over time due to the growth of trees (simulated by the growth of trees into a larger diameter class), the removal of trees due to natural (background) mortality or harvest, and the occurrence of new trees (ingrowth) in the lowest diameter classes. The EFISCEN-Space model is initialised on tree-wise observations from forest inventories, usually National Forest Inventories (NFIs), and driven by environmental datasets with pan-European coverage (Nabuurs et al., 2007, Schelhaas et al., 2022, Filipek et al., In prep). These data are used to initialize forest structure and are the basis for the model's detailed and dynamic (i.e. sensitive to forest structure) simulation of growth (Schelhaas et al., 2018). Growth is related to the current forest structure (plus the abiotic predictors), and as incorporated here under a RCP 4.5. scenario for all baseline (BAU) and restoration scenarios. As the growth functions are fitted on repeated NFIs with a wide range of sites and weather data this results in a climate sensitive growth function. EFISCEN-Space is not a process based model, but it incorporates climate sensitivity by linking its growth functions to annually downscaled weather data from the MPI-ESM1-2-LR global climate model under RCP 4.5. This means forest growth responds to the projected climate changes.

Planting, thinning and final felling can be carried out in EFISCEN-Space according to specified regimes. Natural mortality and harvesting can both be based on fixed regimes (based on repeated forest inventories), and on dynamic modules for natural mortality and ingrowth and simulating harvest using harvest rule patterns. Dynamic modules for mortality and ingrowth are both fitted on large sets of repeated NFI plot and tree wise data (Schelhaas et al in prep; König et al., 2025).

Model outputs provide information about forest resources (growing stock volume, increment, harvested volumes, biomass), carbon pools (biomass, litterfall and soil), biodiversity (number of large size trees, species composition, Gini index, deadwood).

SCENARIO DESCRIPTION

EFISCEN-Space scenarios

For the baseline and two restoration scenarios we used the Swedish NFI (2017 – 2021). In total we simulated 264 plots which represented 813 442 ha of forest area (3% of total Swedish forest area; Figure 2). As the model was initialized on the latest processed NFI data, the model was first simulated to year 2025 with current observed rule management to account for the forest development until 2025. Then the state of the forest in 2025 was used to re-initialize and simulate the demo area from this common point in time until 2055 for each scenario.

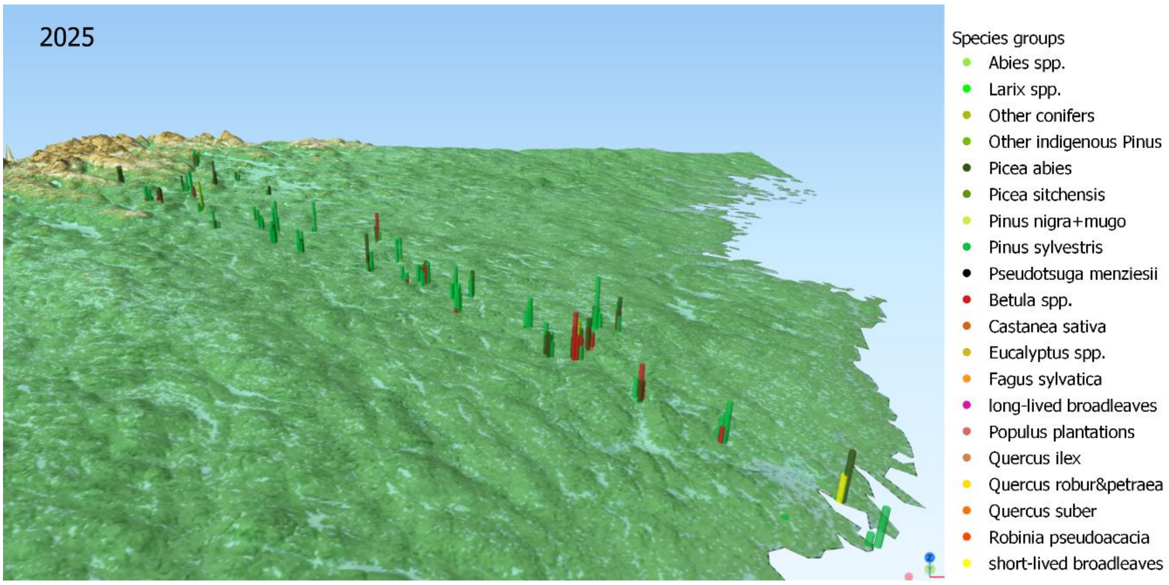

Figure 2. Map of initialized NFI plots in Sweden, in total 264 plots. Colour of the bar represents the initial dominant species or species group per plot, and height of the bar shows the initial growing stock volume (the higher the bar, the larger the growing stock volume).

As forest restoration measures need to be adaptive to climate change, both baseline and restoration scenarios were simulated under climate change scenario RCP4.5 (MPI-ESM1-2-LR). To represent forest dynamics, dynamic ingrowth and mortality were applied to all scenarios.

1. Baseline (BAU)

In the Baseline (BAU) scenario the development of the forest resources under current forest management is simulated. The current forest management was defined based on observed

Sweden harvest rule patterns from two NFI cycles. The harvest rule patterns were described by two types of cutting types: thinning and final felling. The rules patterns were defined by a set of rules which included information about tree species, tree diameter class, stand basal area, number of trees per hectare, country and biogeographical region where forest stand was located (Filipek et al., in prep; Feliciano et al., 2025). Each rule pattern included information about the probability of cutting, its intensity (e.g. amount of basal area removed from the forest stand) and its shape (e.g. thinning from below or from above, which emphasises cuttings of different cohorts of the forest stand diameter distribution).

2. Restoration scenario #1 Dogma shift

In the first alternative restoration scenario there is a shift towards a more varied and biodiversity sustainable use of the forests. Five management strategies can be distinguished and are assigned to a certain area of the forest (Table 1). Under management strategy 1 (MS1), the BAU management is followed. The MS2 strategy focuses on more open forests with more intensive thinnings. Under MS3 an increased planting of birch and short-lived broadleaves is realized. The rotation period is shorter in this scenario. Under MS4 the harvest is delayed and also increased planting of short-lived broadleaves. In general, there is an increase of broadleaf forest in this scenario, meaning less harvesting of broadleaf species. MS5 is an unmanaged management strategy.

Table 1. share of management strategies for scenario 1.

Management strategy	Percentage of forest area
MS1 BAU	22.7%
MS2 Reindeer forest	13.65%
MS3 Prestoration – Intense forestry	0.1%
MS4 Prestoration – close-to-nature	17.75%
MS5 Strict protection	45.8%

3. Restoration scenario #2 Polarisation

In the second alternative restoration scenario, the polarization seen in many areas of society also influences the Swedish forestry. In some parts of the forest leading to more intense forestry, while in other parts owners focus more on biodiversity. Five management strategies can be distinguished and are assigned to a certain area of the forest (Table 2). Under management strategy 1 (MS1), the BAU management is followed. The MS2 strategy focuses on more open forests with more intensive thinnings. Under MS3, there is increased planting of birch and short-lived broadleaves is realized. The rotation period is shorter in this scenario. Under MS4 the harvest is delayed and there is increased planting of short-lived broadleaves. In general, there is an increase of broadleaf forest in this scenario, meaning less harvest in broadleaf species. MS5 is an unmanaged management strategy.

Table 2. share of management strategies for scenario 2.

Management strategy	Percentage of forest area
MS1 BAU	21.05%
MS2 Reindeer forest	3.6%
MS3 Prestoration – Intense forestry	18.75%
MS4 Prestoration – close-to-nature	17.25%
MS5 Strict protection	39.35%

4. Scenario #3 Maximum biomass production, minimum biodiversity concern

In the third alternative restoration scenario the focus is more on biomass production and less on biodiversity with a higher share of MS1 BAU (Table 3). Three other management strategies are used in this scenario. Under MS3 an increased planting of birch and short-lived broadleaves is realized. The rotation period is shorter in this scenario. Under MS4, the harvest is delayed, and there is increased planting of short-lived broadleaves. In general, there is an increase of broadleaf forest in this scenario, meaning less harvest in broadleaf species. MS5 is an unmanaged management strategy.

Table 3. share of management strategies for scenario 3.

Management strategy	Percentage of forest area
MS1 BAU	58.05%
MS2 Reindeer forest	-
MS3 Prestoration – Intense forestry	7.5%
MS4 Prestoration – close-to-nature	3.6%
MS5 Strict protection	30.85%

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PROJECTION RESULTS

EFISCEN-Space

Growing stock

The growing stock (m^3/ha) for the BAU and the three alternative scenarios are shown in figure 3.

The BAU scenario (red) shows the lowest and the most stable growing stock over time. Scenario 1 (blue) and Scenario 2 (green) show a strong and continuous increase in growing stock, mostly influenced by the unmanaged forest areas. Both scenarios reach a growing stock above 160 m^3/ha by 2055. The growing stock in Scenario 3 (yellow) also shows an increase in growing stock, but a more moderate growth compared to Scenario 1 and Scenario 2. By 2055, the growing stock reaches just above 145 m^3/ha.

Overall, all alternative restoration scenarios have a higher growing stock compared to the BAU scenario. Scenario 1 has the highest growing stock (m^3/ha) by 2055.

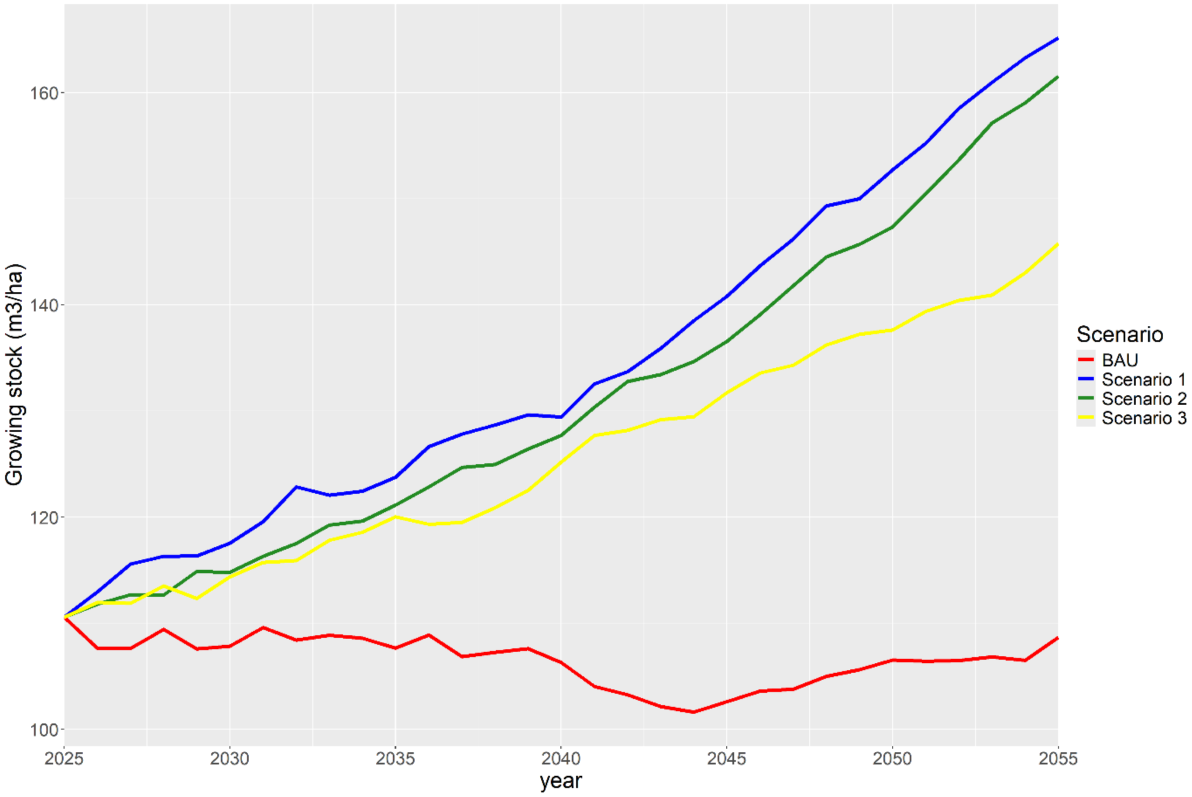


Figure 3 Growing stock (m^3/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3.'

Figure 4 shows the distribution of growing stock (m3/ha) across diameter classes for different tree species, comparing the year 2025 with 2055 for the different scenarios. In 2025, the growing stock is mostly concentrated in the 10-30 diameter classes, mostly composed by *Pinus sylvestris*. In the BAU scenario, there is a shift towards more growing stock in the 30-40 cm diameter class and slightly more towards the larger diameter classes. Scenario 1 and Scenario 2 have in all diameter classes more growing stock compared to 2025 and BAU 2055. The share of short-lived broadleaves in these scenarios is higher in comparison with 2025 and BAU 2055. Scenario 3 has more growing stock in each diameter class compared to 2025 and BAU 2055, but less than Scenario 1 and Scenario 2 in 2055.

In 2055, the share of *Betula* is higher in the BAU and all alternative scenarios compared to 2025. Scenario 1, 2 and 3 have more structural development by 2055 compared to the BAU scenario. The share in short-lived broadleaves is higher in all alternative scenarios compared to the BAU and in 2025.

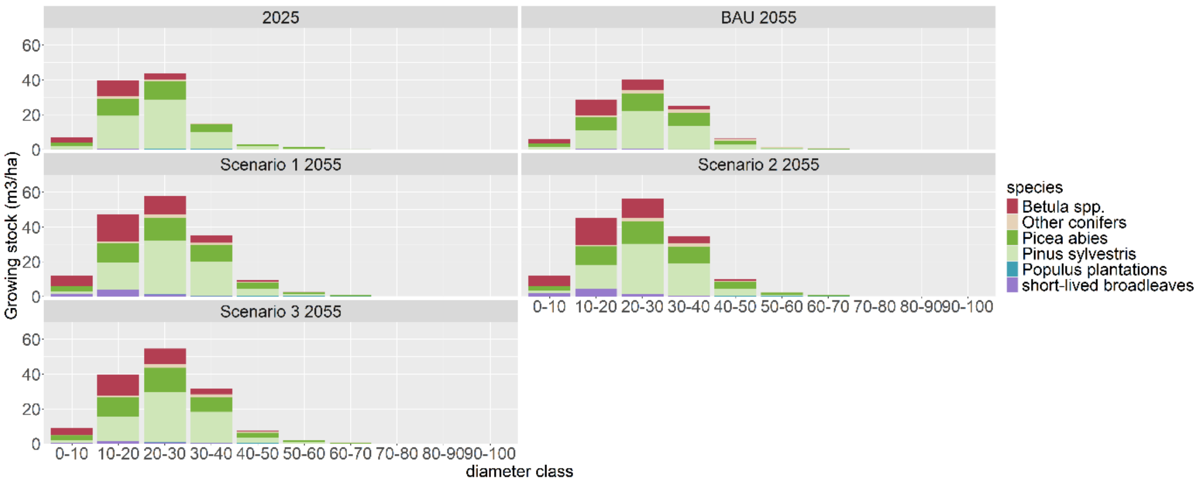


Figure 4 Growing stock (m3/ha) per species and diameter class for the year 2025 and for the different scenarios in 2055

Increment

The gross increment (m3/ha/yr) for the BAU scenario and the three alternative scenarios is shown in figure 5. The BAU (red) increment is quite stable in the first couple of years, after which it starts declining until around year 2043. From 2043 till 2055 the gross increment recovers. By 2055 the increment nearly reaches 3.5 m3/ha/yr under the BAU scenario. Scenario 1 (blue) and scenario 2 (green) follow a similar increasing trend. The increment is higher compared to the BAU scenario, from 2045 onwards, around 1 m3/ha/yr higher. In 2055, both scenarios have an increment a bit higher than 4.5 m3/ha. Scenario 3 (yellow) has a higher increment during the simulation period compared to the BAU scenario. It is stable until around 2045. From 2045 onwards the increment increases to around 4 m3/ha/yr.

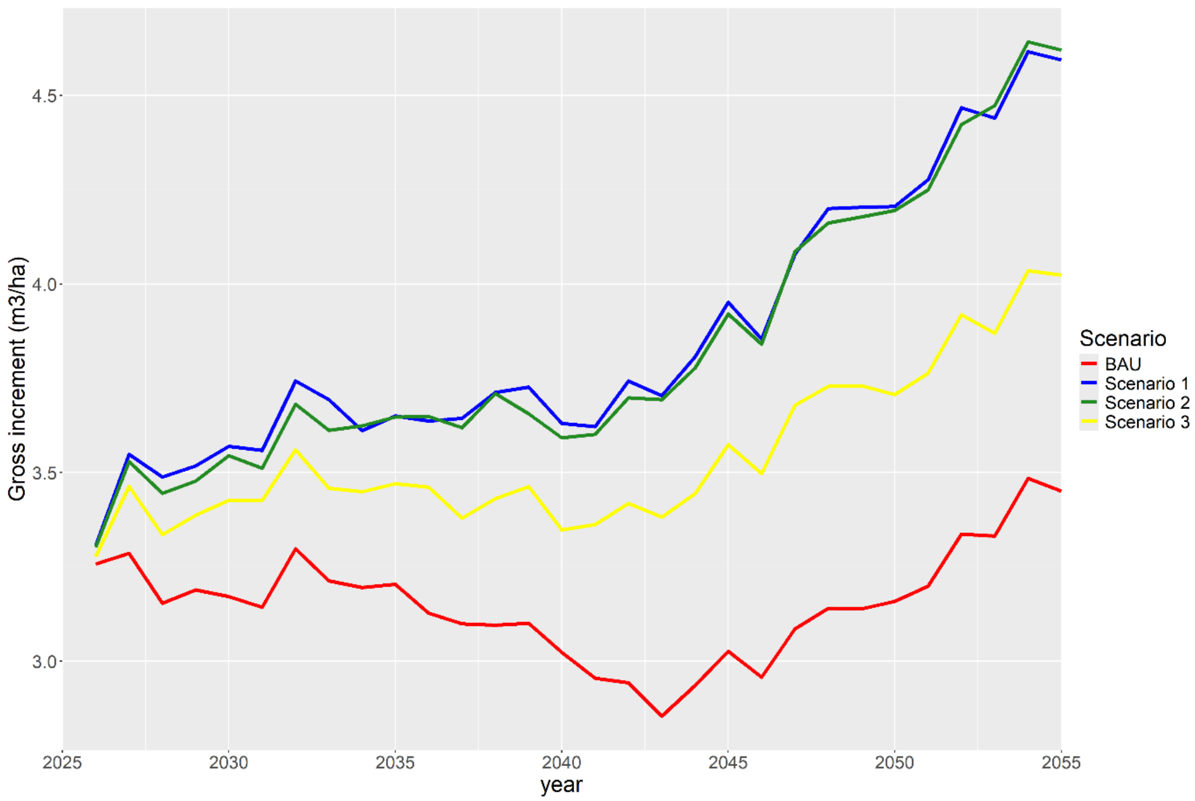


Figure 5 Gross annual increment (m3/ha) over time for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3.

Harvest

Figure 6 shows the harvest (m³/ha) from 2025 till 2055 for the BAU scenario and the three alternative scenarios. The wood harvest fluctuates over the simulated time period for all scenarios. More or less volume is harvested depending on how many trees grow into the harvestable thresholds in the scenarios and the harvest intervals.

Scenario 1 and 2 have low harvest levels compared to the BAU scenario and Scenario 3. The share of unmanaged forest in these scenarios is higher. Although Scenario 2 has a higher share of prestoration – intense forestry, Scenario 1 has a higher share of reindeer forest, where more thinnings are taking place for openness. This means in the end similar average harvest over the entire period, with Scenario 1 having a slightly lower average harvest (1.66 m³/ha/yr compared to 1.75 m³/ha/yr). The BAU scenario has the highest average harvest (2.8 m³/ha/yr). The average harvest of Scenario 3 is 2.02 m³/ha/yr being in-between the harvest levels of the BAU scenario, and Scenario 1 and Scenario 2. This is caused by a higher share of forest that keeps the BAU management strategy and less unmanaged forest.

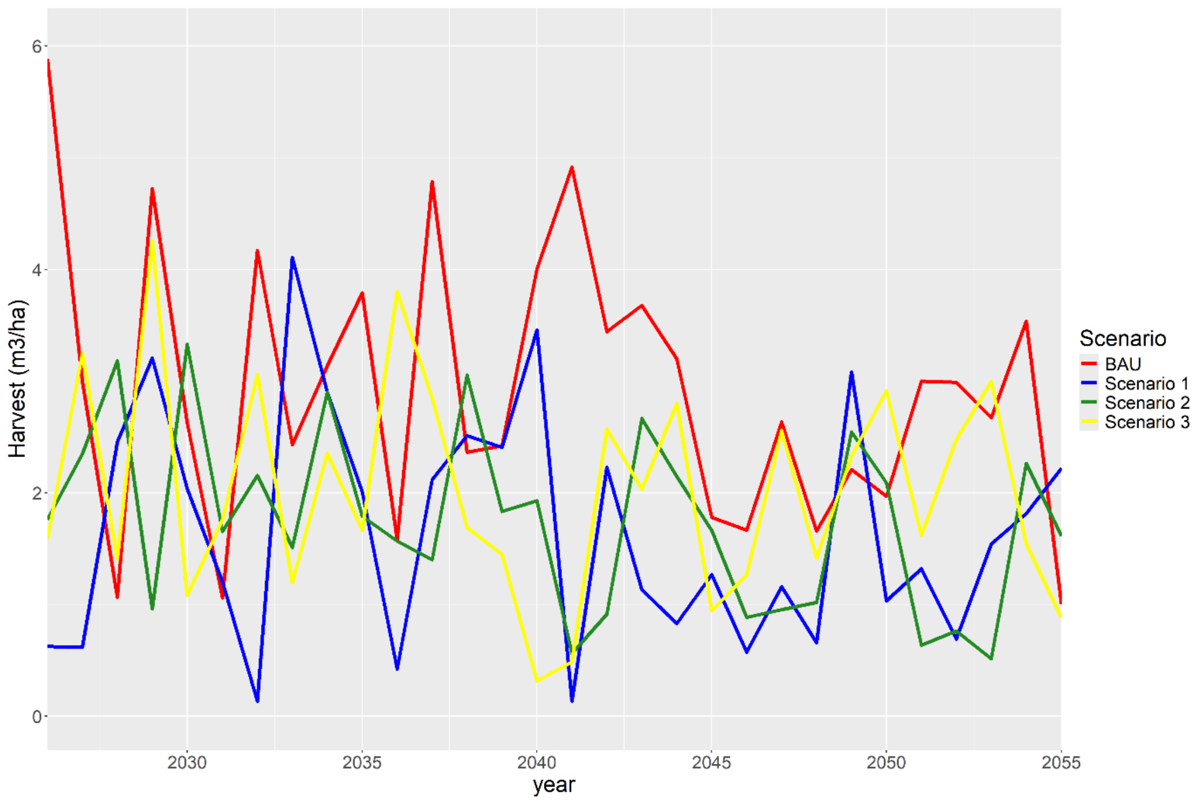


Figure 6 Harvested volume (m³/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3.

Mortality

Figure 7 presents the average annual mortality (m³/ha/yr) across diameter classes for the four scenarios. Mortality in the BAU scenario is lower across all diameter classes compared to the alternative scenarios, mainly because a larger area is harvested. In the alternative scenarios, more areas are set-a-side, left unharvested, allowing natural mortality to occur more frequently.

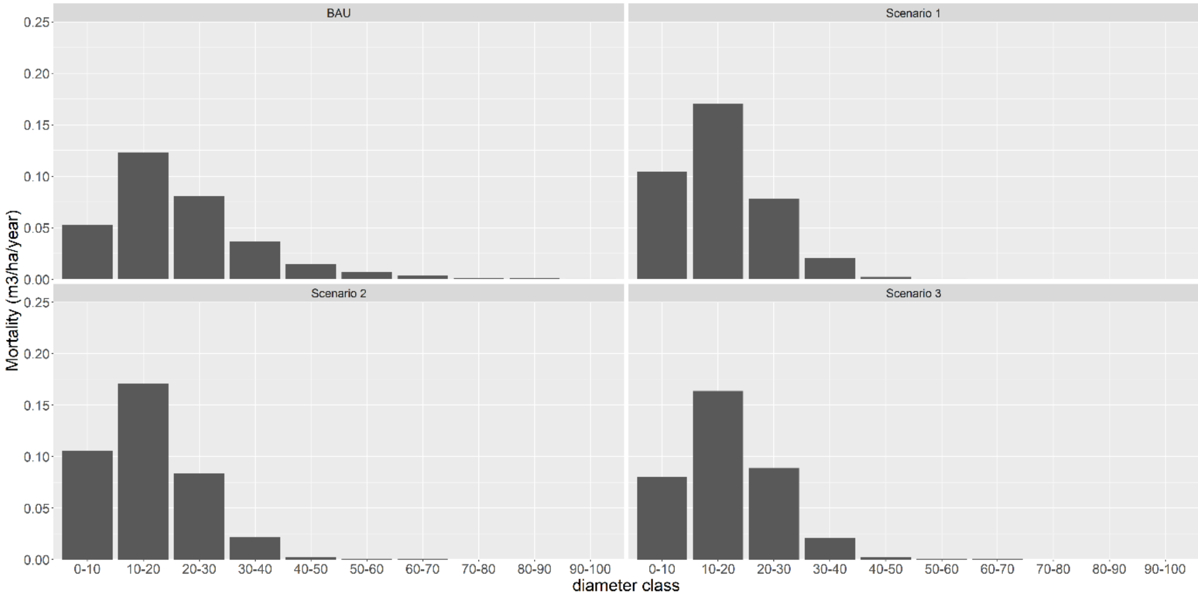


Figure 7 Mean mortality (m3/ha/year) development over diameter classes (cm) for the three different scenarios. Mortality is estimated as the average over the 30-year simulation (from 2025 till 2055).

Gini index

Figure 8 shows the Gini index over time (2025 – 2055) for the four different scenarios. The Gini index over time for each scenario is displayed in figure 8. The Gini diversity index quantifies structural heterogeneity and is here applied to the diameter. A higher Gini index indicates greater heterogeneity in the distribution of tree sizes, indicating a more complex and heterogeneous forest structure. The Gini index increases across all scenarios. BAU (red) has the lowest Gini during the entire simulation period. Scenario 1 (blue) and Scenario 2 (green) have similar Gini, with Scenario 2 performing a bit better from 2035 onwards. Scenario 3 also shows an improvement in the Gini, but not as strong as the other alternative scenarios ending just above 0.50.

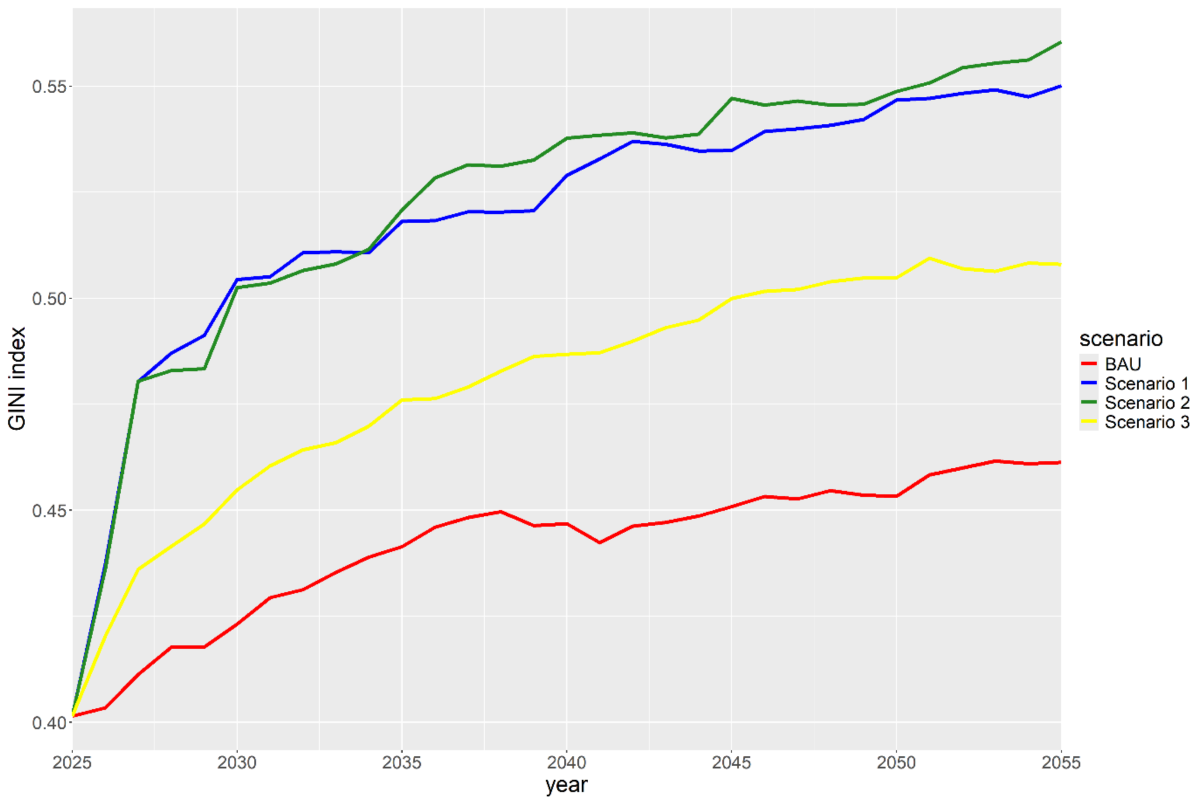


Figure 8 Gini index (inequality index) development for the three different scenarios over time. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3.

Soil organic carbon

Figure 9 shows the development of soil organic carbon stock (SOC) (ton C/ha) over time. EFISCEN-Space uses Yasso15 to model the SOC. In Yasso15 a spin-up phase is used to bring the SOC into equilibrium based on the described scenarios, resulting in different starting conditions.

The BAU scenario has a quite stable SOC. Throughout the entire simulation period, the SOC level remain between 135 and 140 ton C/ha. Scenario 1, Scenario 2 and Scenario 3 follow a similar pattern, showing a stable increase. All alternative scenarios have a higher SOC compared with the BAU scenario, with Scenario 1 having the highest SOC throughout the simulated period.

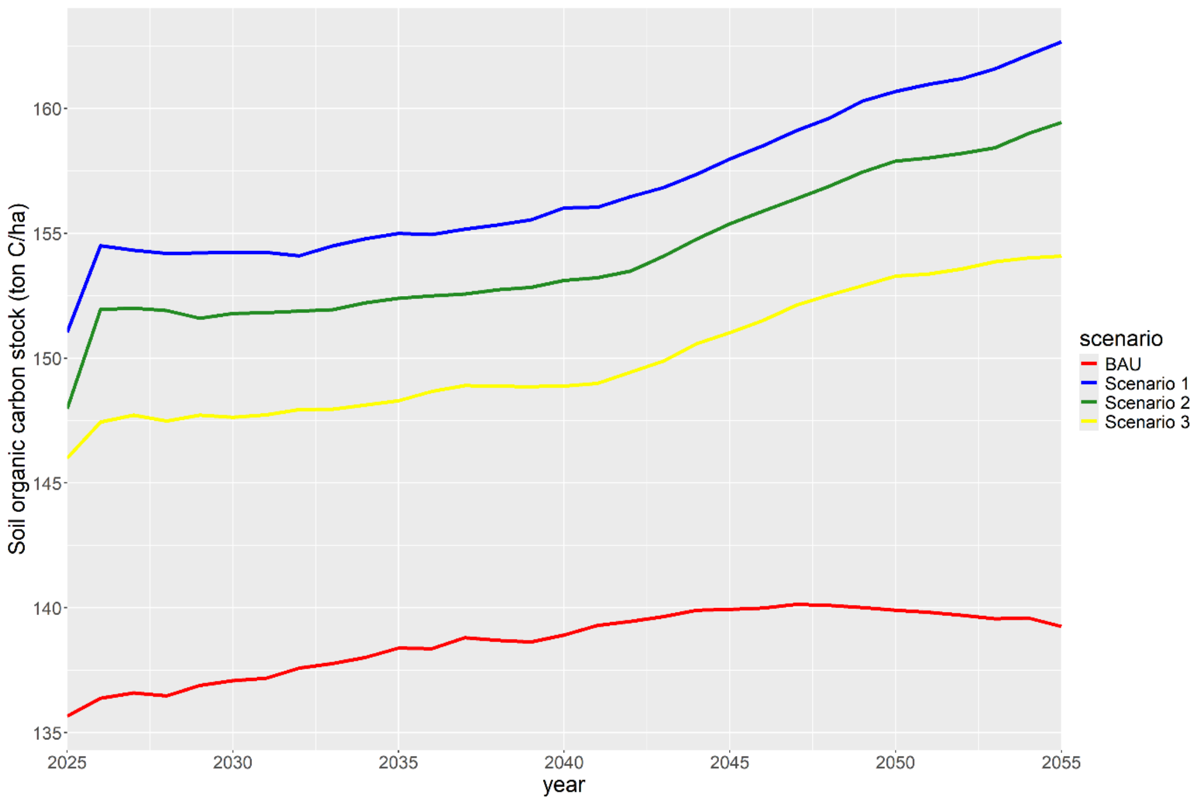


Figure 9 Soil organic carbon (SOC; ton C/ha) development over time for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3. The SOC was simulated using Yasso15 model (Järvenpää et al., 2018) coupled with EFISCEN-Space.

KEY FINDINGS

Key finding #1

A comparison of the scenarios in the Swedish demo area (813 442 ha) shows that the baseline (BAU) scenario has a stable but relatively low growing stock, the restoration scenarios, especially scenario 1 (Dogma shift) and scenario 2 (polarization), lead to higher growing stock, higher gross increment, and greater structural diversity (as shown by the Gini index). This is largely due to increased areas of unmanaged or less intensively managed forest and a higher share of broadleaved species. Scenario 3 also shows improvement, but to a lesser extent due to a stronger emphasis on biomass production.

Key finding #2

The BAU scenario maintains the highest average harvest volume (2.8 m^3/ha/year), reflecting intensive and consistent forest management. Alternative scenarios 1 and 2, which have a higher share of area allocated to protection and closer-to-nature management, result in lower harvest levels (around 1.7 m^3/ha/year), and have more natural dynamics, including higher natural mortality and increased biodiversity potential. Scenario 3 sits in the middle, having the largest share of forest managed as in the BAU of the three alternative scenarios.

Key finding #3

In all alternative scenarios, the share of unmanaged forest increases compared to the BAU scenario. Unmanaged forests lead to a significant increase in growing stock in the simulated scenarios.

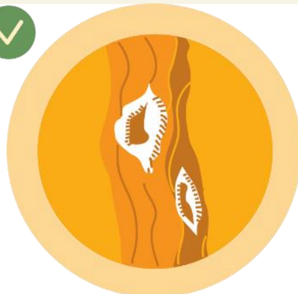
RECOMMENDATIONS

Takeaway #1

None of the alternative scenarios were able to maintain the harvest levels of the BAU scenario, however the species composition, structural composition and increment increased in the alternative scenarios, creating more diverse forests.

Takeaway #2

Unmanaged forest lead in these stands to a larger growing stock and thus carbon storage, however creating a more diverse and resilient forest requires interventions such as thinnings and planting.



Takeaway #3

Creating a more species diverse forest by increasing the share of broadleaves in a coniferous-dominated forest takes time but provides continuous biodiversity advantages in the long-term.

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