



FORWARD PROJECTIONS

THE NETHERLANDS



SUPERB
Upscaling Forest Restoration



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EXECUTIVE SUMMARY

The forests in the Dutch demo area are still relatively young, located in an intensive agricultural landscape. The main restoration actions focus on revitalizing existing forests, particularly fragmented old *Pinus sylvestris* plantations. The revitalization measures focus on transitioning degraded forests into more diverse and complex ecosystems, with the aim to facilitate the improvement of soil conditions, thereby increasing tree vitality and overall ecosystem functionality.

This Dutch demo 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, till 2055 using the EFISCEN-Space model under RCP 4.5.

Four scenarios are simulated. In the business as usual (BAU) scenario, forest development under current management is simulated. In the first and second restoration scenario, a doom scenario is simulated, in which all *Pinus sylvestris* die off. In restoration scenario 1, no investments are made in planting new trees, while in restoration scenario 2, young trees are planted. In the final scenario, restoration scenario 3, the SUPERB restoration actions are simulated on a larger scale.

The models' projections show that both BAU and scenario 3 result in similar development. However, in scenario 3, the share of one dominant species is smaller, which makes it a more resilient forest for the future, and with the planting of rich litter species, forest soil conditions improve. Since different strategies lead to varied outcomes, restoration should be tailored towards the desired restoration goals. Planting new species can help create a more diverse and resilient forest, better adapted to future conditions, and introduce species that are not yet to be found in the forest.

DEMO INFORMATION

The Dutch demo is located in the southern part of the Netherlands (province of Limburg) within a mosaic of forest and agricultural land. Thick layers of sandy soils, deposited by rivers, characterize the southern and eastern regions. Historically, extensive forests covered these lands, but today, forests are small and young, existing within an intensively used agricultural landscape. Before 1900, the southern sandy soils were predominantly used for extensive agriculture, with heathlands covering much of the landscape. To improve crop growth, sods from the heathlands were harvested and spread over fields, further degrading soil quality. However, in the early 20th century, significant landscape transformation occurred due to the availability of artificial fertilizers and the increasing demand for timber, particularly in coal mines. This led to vast areas of former heathlands being planted with trees, *primarily Pinus sylvestris* and *Quercus robur*, while other parts transitioned to intensified agricultural use. Consequently, a great difference in soil quality emerged between forests and arable lands, with forests experiencing acidification and nutrient imbalances, impacting tree vitality and biodiversity (Figure 1).



Figure 1. Landscape and internal appearance of *Pinus sylvestris* dominated forests.



Restoration measures in the Dutch demo address various challenges while enhancing forest ecosystems' resilience and functionality. The degradation of the abiotic system, including hydrological changes, acidification, and nutrient imbalances, poses significant challenges to forest ecosystems. Therefore, the main restoration actions focus on revitalizing existing forests, particularly fragmented old *Pinus sylvestris* plantations. The revitalization measures focus on transitioning degraded forests into more diverse and complex ecosystems, with the aim to facilitate the improvement of soil conditions, thereby increasing tree vitality and overall ecosystem functionality.

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 to a larger diameter class), the removal of trees due to natural (background) mortality or harvest, and the occurrence of new trees (ingrowth) in 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

For the Baseline and three alternative scenarios, we used a subset of the Dutch NFI7 (2017 – 2022) measured in two provinces; Noord-Brabant and Limburg. The plots in Southern Limburg (South from Sittard) were excluded, as this area has different soils and forest types. In total we simulated 872 plots representing approximately around 99 757 ha of forest area (around 27% of the total Dutch forest area). All runs are simulated from the year 2025 to 2055. Since our input NFI cycle ended in 2022, the model was first used to simulate the forest resources till the initial year 2025. Then, the state of the forest in 2025 was used to re-initialize and simulate the demo from this point in time until 2055 for each scenario.

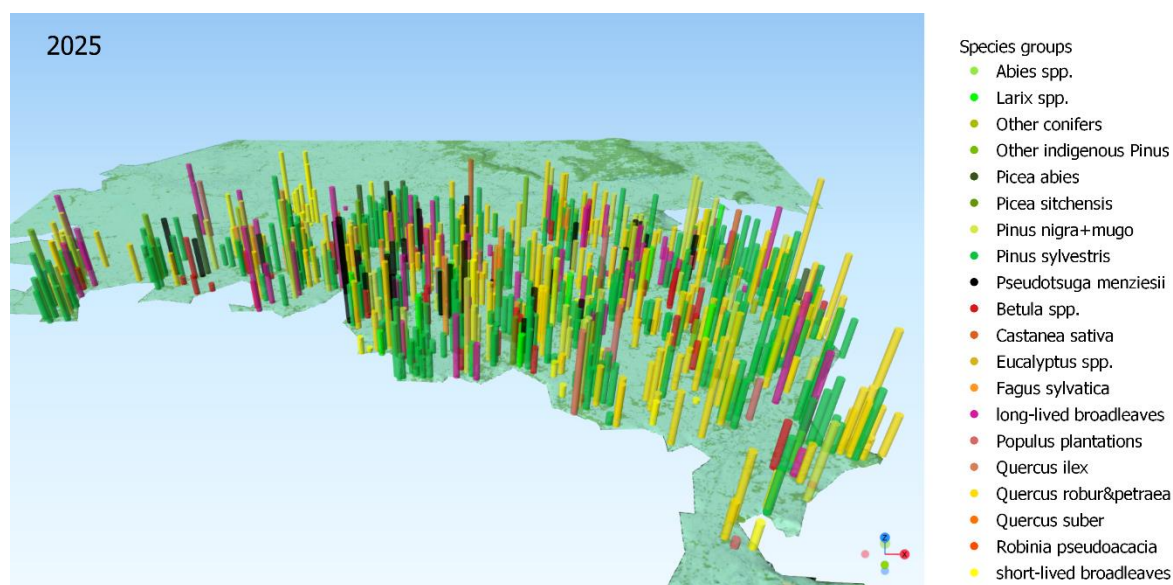


Figure 2. Map of initialized NFI plots in Dutch demo, in total 923 plots. Colour of the bar represents the initial dominant species or species group per plot, and height of the bar shows the initial growing stock volume (the higher the bar, the larger the growing stock volume).

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 (business as usual (BAU)) scenario the development of the forest resources under current forest management is simulated. The current forest management was defined based on observed Dutch harvest rule patterns from two NFI cycles (NFI-6 and NFI-7). The harvest rule patterns were described by two types of cutting operations: 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 the forest stand was located (Filipek et al., in prep; ForestPaths D1.3). 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 Doom scenario without planting

In the first restoration scenario, the simulation begins with a catastrophic event: in 2030, all Scots pine trees die off. This catastrophic event is simulated because species distribution models predict that under climate change scenarios Scots pine will no longer be suited to this area. While this is the most planted tree in the past this will be a disaster for the forests.

Following this calamity, passive restoration is implemented. No planting takes place, and forest recovery relies entirely on natural regeneration. For the other forest types, management practices remain the same as in the BAU scenario.

3. Restoration scenario #2 Doom scenario with planting

In the second restoration scenario, the simulation also starts with the same catastrophic event: in 2030, all Scots pine trees die off. Following this calamity, active restoration is implemented to restore more diverse forests. In this scenario, a mixed forest is planted after the calamity in 2030 to influence the species composition and make sure that a mixed forest will develop. The planting density is 2000 trees per ha, with 30% oak, 10% Douglas, 20% short-lived broadleaves and 40% long-lived broadleaves (Table 1).

Species(group)	Trees per ha planted
Oak	600
Douglas	200
Short-lived broadleaves	400
Long-lived broadleaves	800

4. Restoration scenario #3 SUPERB planting

To avoid such doom scenarios, it is important to act now by creating more diverse forests that are more resilient for future challenges. This approach is being implemented in the Dutch demo area of the SUPERB project.

In the SUPERB planting scenario, the planting scheme of the Dutch demo is simulated. On average 100 trees per ha are planted of which 20% are oak, 20% are short-lived broadleaves and 60% are long-lived broadleaves (Table 2). Scots pine is harvested more intensely to make space for these broadleaved species. This is done until 2030, after which harvesting is reduced and the planted trees get the chance to grow.

Species(group)	Trees per ha planted
Oak	20
Short-lived broadleaves	20
Long-lived broadleaves	60

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PROJECTION RESULTS

Growing stock

The growing stock development (m^3/ha) over time (2025 till 2055) of the four different scenarios are shown in figure 3. Scenario 1 and Scenario 2 follow the same development as the BAU scenario for the first 5 years.

The growing stock of the BAU (red) scenario steadily increases from around $237 \text{ m}^3/\text{ha}$ in 2025 to around $315 \text{ m}^3/\text{ha}$ in 2055, due to a high increment and the harvested volumes being lower than the increment. Scenario 1 (blue) and Scenario 2 (green) start with the same increase for the first 5 years. In 2030 the calamity happens in which all Scots pine die off. Both scenarios follow a similar increase in growing stock after 2030. No differences can be seen in active planting and ingrowth (Scenario 2) and only ingrowth (Scenario 1) in terms of growing stock. The growing stock (m^3/ha) in Scenario 3 (yellow), where no calamity happens and where at the beginning of the simulation restoration actions happen, shows a small decline at first, due to creating space for the newly planted trees, after which the growing stock recovers.

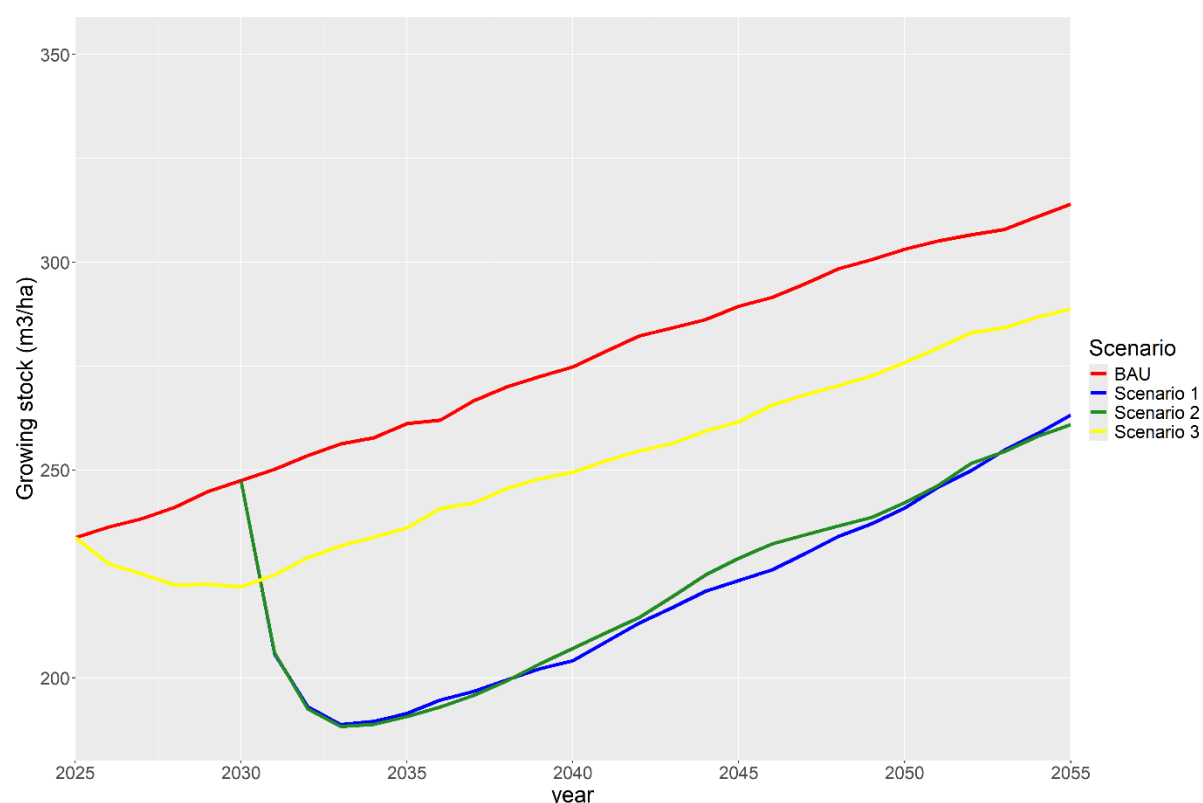


Figure 3 Growing stock (m^3/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3. Scenario 1 and Scenario 2 follow the BAU the first 5 years.

Figure 4 shows the distribution of growing stock (m^3/ha) across diameter classes for different tree species, comparing the year 2025 with 2055 for the different scenarios. In 2025, the growing stock is concentrated in the 20 - 50 cm diameter classes. The dominant species is

Pinus sylvestris. By 2055, under the BAU scenario, a shift can be noticed in the growing stock towards the 30-60 cm diameter classes with the main species(groups) being *Pinus sylvestris* and *Quercus robur & petraea*.

In Scenarios 1 and 2, catastrophic events are simulated in which all Scots pine trees die in 2030. As a result, this species is no longer present by 2055 in these scenarios. In the smaller diameter classes, an increase in *Betula* and other long-lived broadleaves species is observed.

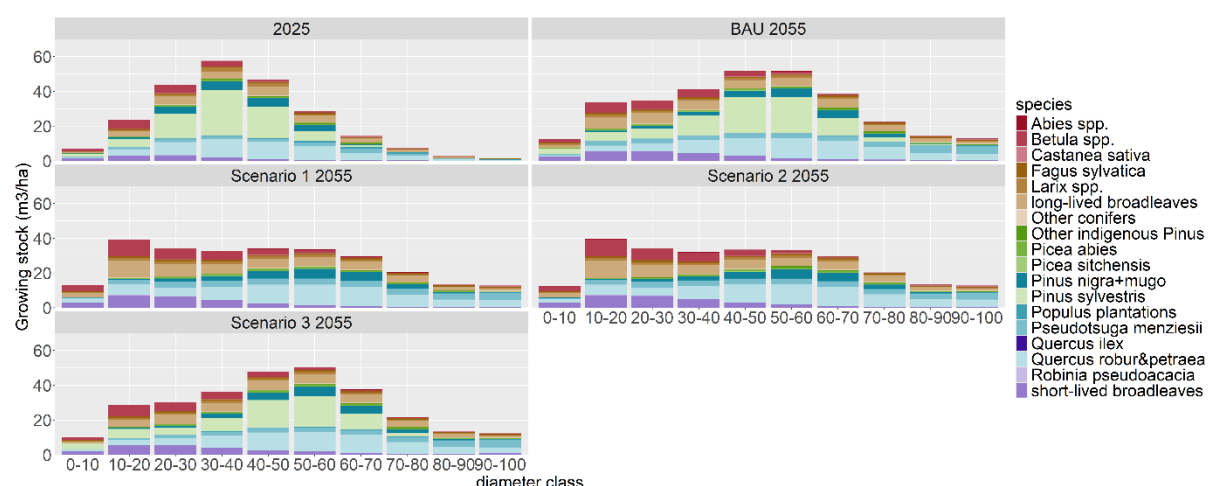


Figure 4 Growing stock (m³/ha) per species and diameter class for the year 2025 and for the different scenarios in 2055

Scenario 3 looks very similar to the BAU scenario. However, the growing stock is slightly lower due to opening up the forest for newly planted species. The planting density is low in scenario 3, which is why the growing stock is lower, but new species are brought in to make the forest more resilient.

Increment

Figure 5 shows the gross increment (m³/ha/yr) for the four scenarios. Scenario 1 and Scenario 2 follow the same pattern for the first five years as the BAU scenario. The increment of the BAU scenario increases steadily until around 2037, after which it fluctuates slightly and ends at approximately 9.4 m³/ha/yr in 2055. The number of trees in the diameter classes from 20-40 is much lower in 2055 compared to 2025 and there are more younger and older trees that can be found. In Scenario 1 and 2, the increment also increases until 2035, like the BAU scenario, but both experience a drop in increment caused by the calamity affecting Scots pine. From 2035 onwards the increment begins to recover. Scenario 1 leads to a slightly higher increment in 2055, but the differences are very small. The gross increment in Scenario 3 fluctuates between around 8 and 8.5 m³/ha/yr. The increment is lower compared to the BAU scenario and it is also lower compared to Scenario 1 and Scenario 2. Until 2030 space is made for the newly planted trees after which the increment recovers.

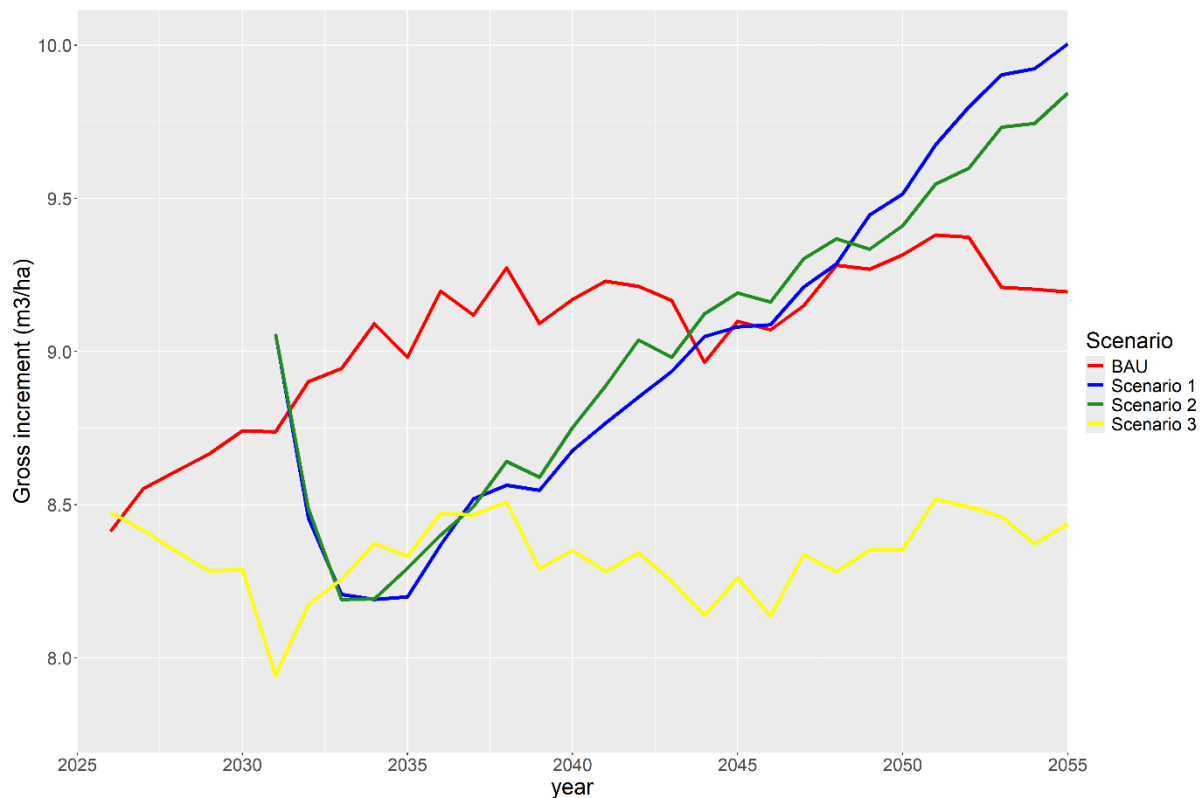


Figure 5 Gross annual increment (m^3/ha) over time for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3. Scenario 1 and Scenario 2 follow the BAU the first 5 years

Harvest

The harvest (m^3/ha) for the four scenarios is shown in figure 6. The harvest levels in scenario 1 (blue), 2 (green) and BAU (red) are similar until 2035. The wood harvest fluctuates over the simulated time period for all scenarios, influenced by the number of trees reaching harvestable size and the timing of harvest intervals.

The BAU scenario (red) and Scenario 3 show a similar average harvest of around $5.2 \text{ m}^3/\text{ha}/\text{yr}$, with scenario 3 having a peak in the first years. Scenario 1 and Scenario 2 have a lower average harvest of respectively, 3.67 and $3.74 \text{ m}^3/\text{ha}/\text{yr}$. Due to the calamity in the year 2030, the harvestable volumes are lower in these scenarios. In addition, the planted and natural regeneration has not yet reached harvestable size. In Scenario 3, the harvest is focused on creating space for the underplanting.

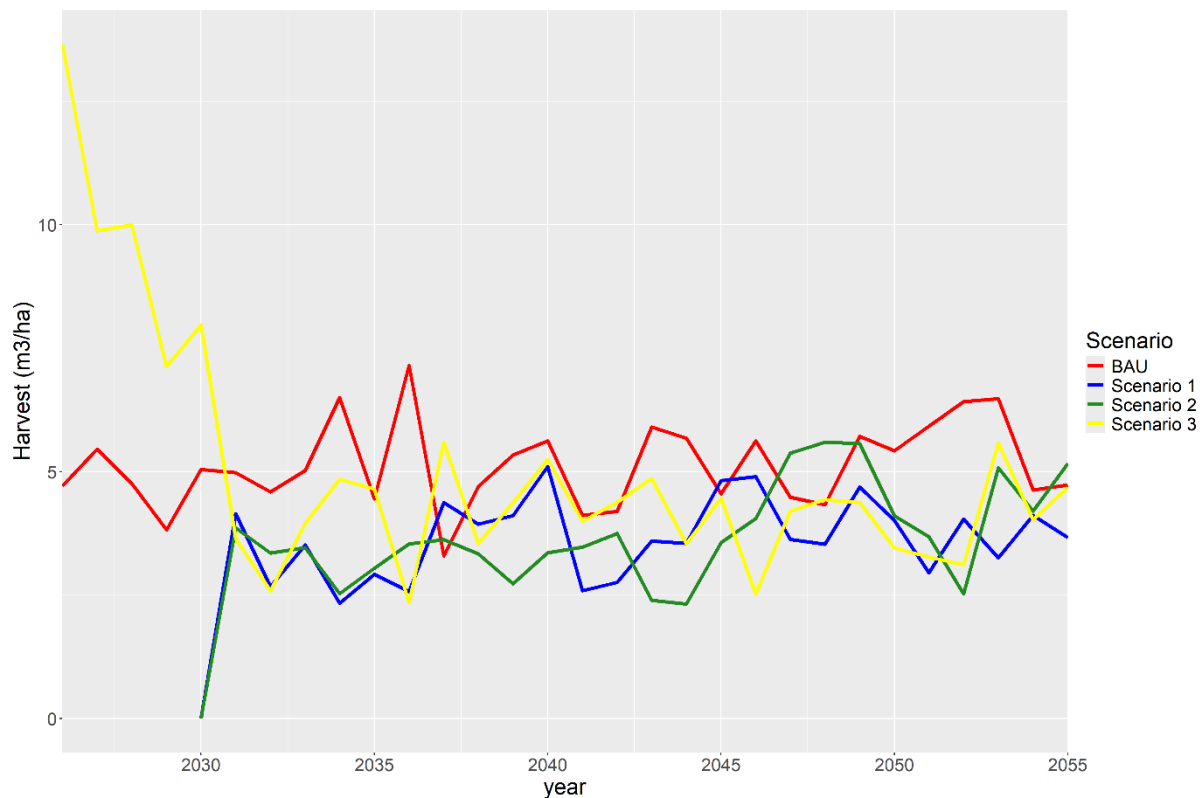


Figure 6 Harvested volume (m^3/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3. Scenario 1 and Scenario 2 follow the BAU the first 5 years

Mortality

Figure 7 presents the average annual mortality ($\text{m}^3/\text{ha}/\text{yr}$) across diameter classes for the four scenarios. The average mortality is higher in Scenario 1 and Scenario 2, compared to the other two scenarios, due to the die-back in Scots pine. In all scenarios there is also mortality in the larger diameter classes, indicating dead wood of larger trees.

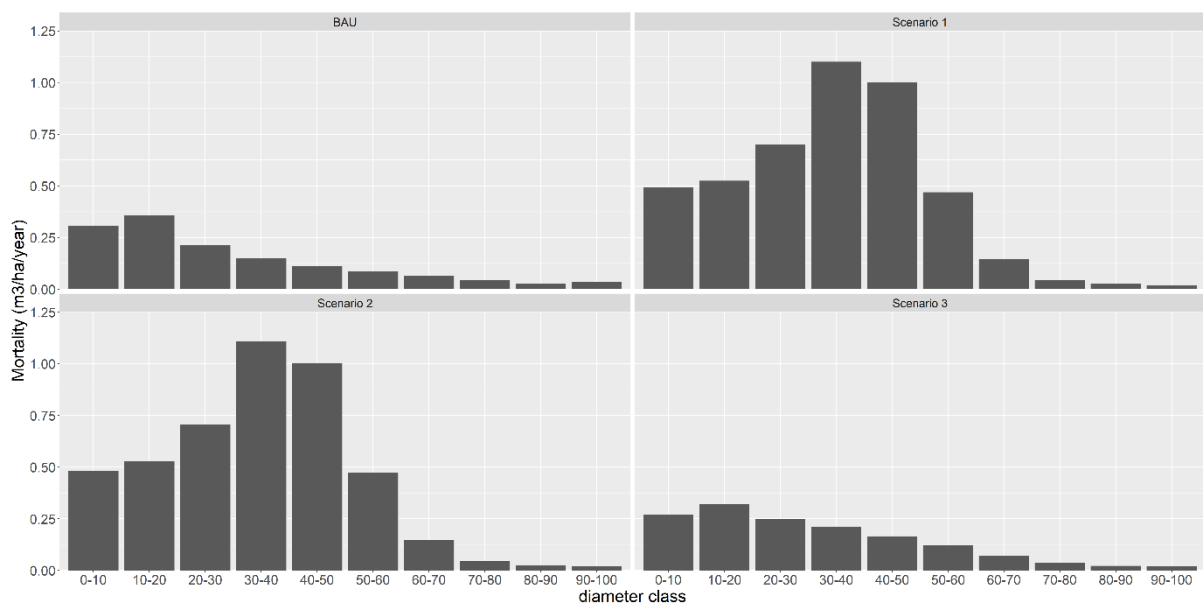


Figure 7 Mean mortality ($\text{m}^3/\text{ha}/\text{year}$) development over diameter classes (cm) for the three different scenarios. Mortality is estimated as the average over the 30-year simulation (from 2025 till 2055).

Gini index

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, heterogeneous forest structure. A Gini index below 0.50 indicates a more homogenous (less complex) forest structure. This is calculated on the plot level. Scenario 1 (blue) and Scenario 2 (green) follow the same line as the BAU (red) scenario till 2030. The BAU scenario (red) has a stable Gini for most of the simulated period just above 0.55. Scenario 3 (yellow) follows a similar pattern as the BAU scenario, but just slightly higher. The calamity first causes an increase in the Gini. But the Gini decreases rapidly ending for both Scenario 1 and Scenario 2 below the BAU scenario and Scenario 3, due to a more even distribution over the diameters.

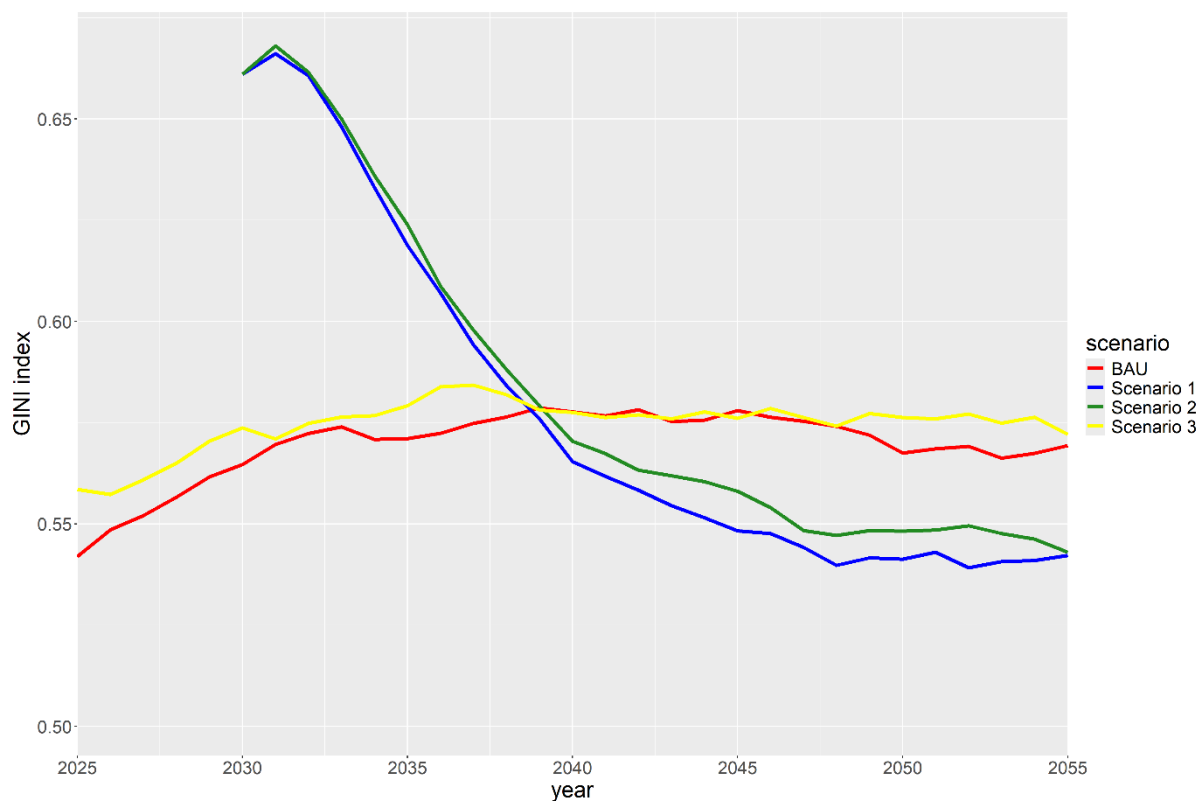


Figure 8 Gini index (inequality index) development for the three different scenarios over time. In red BAU scenario, in blue Scenario 1, in green Scenario 2 and in yellow Scenario 3. Scenario 1 and Scenario 2 follow the BAU the first 5 years

KEY FINDINGS

Key finding #1

Under the BAU scenario and alternative scenarios, almost 100 000 ha of forest in the Netherlands is simulated. The BAU scenario results in a steady increase in growing stock and gross increment. Trees are getting larger and the forest structure is getting more diverse. However, a large part of the forest is still dominated by Scots pine.



Key finding #2

In both Scenario 1 (passive restoration) and Scenario 2 (active restoration), a simulated calamity causes the sudden dieback of Scots pine in 2030. This event leads to immediate drops in growing stock, increment, and harvest volumes. Natural regeneration (Scenario 1) and replanting with mixed species (Scenario 2) help forests recover. These scenarios show the vulnerability of forests to climate change and the importance of acting, like in scenario 3, the SUPERB scenario.



Key finding #3

Scenario 3 (SUPERB planting) creates a more resilient forest to avoid catastrophic events. Scots pine are replaced by a more diverse broadleaved species with a focus on rich litter to create a healthier forest soil. Although growing stock and increment are slightly lower due to low planting densities and initial thinning, this approach improves structural diversity and species composition by introducing new species with the ability to improve the forest soil.



RECOMMENDATIONS

Takeaway #1

Both BAU and Scenario 3 show similar development. However, in scenario 3 the share of one dominant species is smaller, which makes it a more resilient forest for the future. The planting of rich litter species, as done in the SUPERB project but not clearly reflected in the results here, further improves the forest by supporting healthier soil conditions and introducing new species that were not previously found in the forest.



Takeaway #2

For a fast recovery and a resilient forest after calamity, both planting and natural regeneration can be considered with planting having more influence on the future species composition. By restoring forests today, like in the SUPERB project, these catastrophic events can be avoided.



Takeaway #3

Since different strategies lead to varied outcomes, restoration should be tailored towards the desired restoration goals. Planting new species can help create a more diverse and resilient forest, better adapted to future conditions, and introduce species that are not yet to be found in the forest.



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