



FORWARD PROJECTIONS

FRANCE



SUPERB
Upscaling Forest Restoration



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EXECUTIVE SUMMARY

The Landes of Gascony Forest is located in the South-West of France, in the Nouvelle-Aquitaine administrative region. This territory of 1.5 million hectares is the most forested in France (74% afforestation rate), and 90% of this forest area is dominated by intensively managed monospecific plantation of native *Pinus pinaster* to enhance the resilience of these forests hedgerows of broadleaved species are established in this area.

This French 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, with use of the EFISCEN-Space model.

Five scenarios are simulated with EFISCEN-Space: a business-as-usual (BAU) scenario and 4 restoration scenarios. In the business-as-usual scenario, the forest development is simulated under current management regimes. In the first restoration scenario, 10% of the previous dominated maritime pine plots are planted exclusively with oak. In the second restoration scenario, 10% of the previous dominated maritime pine plots are planted exclusively with birch. In the third restoration scenario, inside all plots dominated by maritime pine 10% is planted with oak. In the fourth restoration scenario, birch is planted inside 10% of all plots dominated by maritime pine.

The model projections showed that alternative scenarios 3 and 4 improve forest structure and species composition and maintaining the initial level of increment throughout the simulation period proves challenging across all scenarios. Also, in these monocultures, even small interventions can already enhance both species composition and structural diversity which make the forests more resilient for the future.



DEMO INFORMATION

The Landes of Gascony Forest is located in the South-West of France, in the Nouvelle-Aquitaine administrative region. Formerly a wetland occupied by extensive sheep farming, the area was strongly afforested in the 1900s under Emperor Napoleon III. Today, this territory of 1.5 million hectares is the most forested in France (74% afforestation rate), and 90% of this forest area is dominated by intensively managed monospecific plantation of native *Pinus pinaster* (Maritime pine; Figure 1). The Maritime pine species is of great socio-economic importance, as its management generates jobs, provides a large share of the national harvest of wood used for various products, and is strongly linked to the identity of the landscape and the attractiveness of the region. However, the region is characterized by specific abiotic pressures such as forest fires (with the highest rate of fire outbreaks in France), windstorms (with two hurricanes in 1999 and 2009 destroying 30% of the forest wood stock) and biotic pressures with bark beetle outbreaks and feared biological invasions of the pine wood nematode.



Figure 1. Landscape and internal appearance of intensive *Pinus pinaster* plantations.

To enhance the resilience of intensive plantations and address pressing environmental concerns, restoration actions aim to diversify tree species composition. However, to maintain the forests productivity and the commitment of the forest owners, the implementation of the diversified tree species is established in hedgerows along Maritime pine plantations. The established hedgerows aim to promote biodiversity, increase forest resilience, and mitigate the impacts of climate change-mediated disturbances such as forest fires, windstorms, and biological invasions.

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

EFISCEN-Space scenarios

For the baseline and alternative scenarios we used a subset of the French NFI-7 (2017–2021) measured in Landes (Figure 2). In total we simulated for the baseline scenario 1546 plots which represent 867 716 ha of forest area (around 5% of the total French forest area).

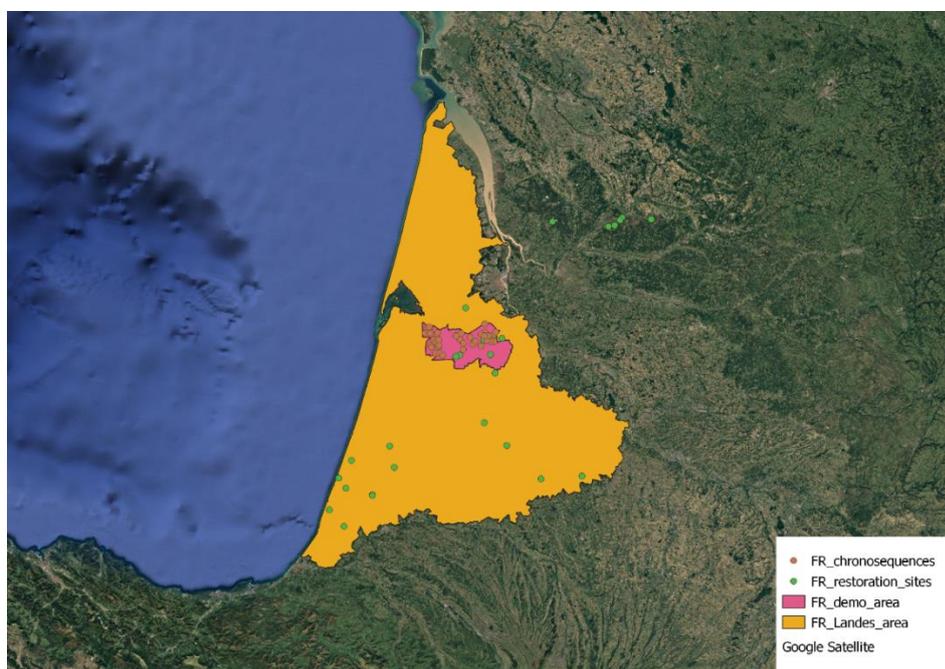


Figure 2. Map of the Landes, the larger French demo area (yellow).

As the model was initialized on the latest processed NFI data, it was first simulated to year 2025 with business-as-usual management to account for the forest development until 2025 (Figure 3). Then the state of the forest in 2025 was used to re-initialize and simulate the demo area from this common point in time considering other SUPERB demos.

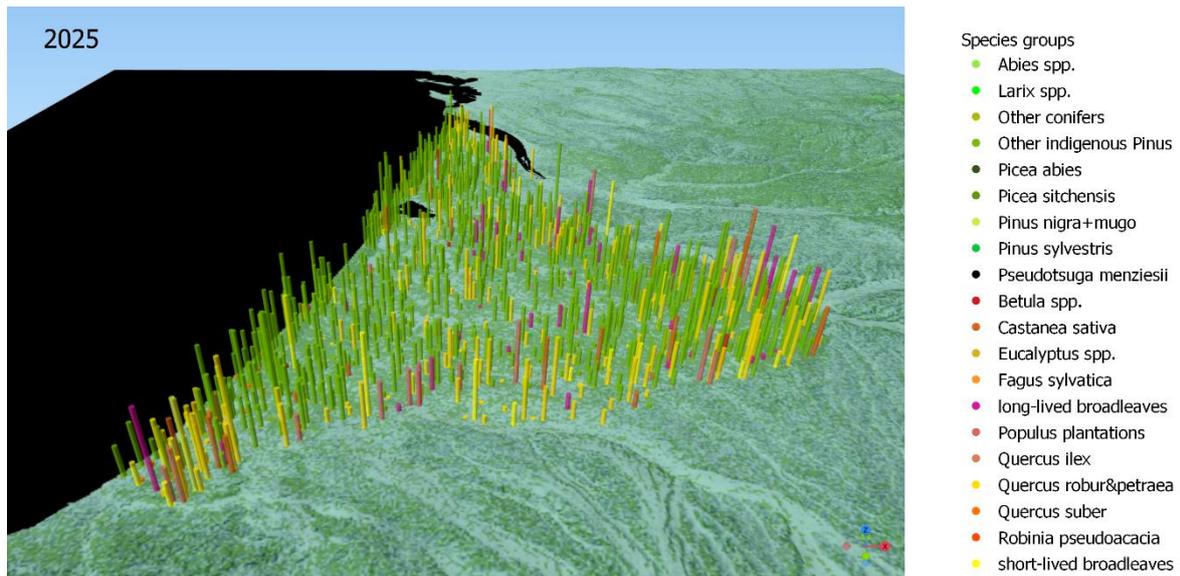


Figure 3. Map of initialized NFI plots in France, in total 1 546 plots. Colour of the bar represents the initial dominant species or species group per plot, and height of the bar shows the initial growing stock volume (the higher the bar, the larger the growing stock volume).

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-HR).

To represent forest dynamics, dynamic ingrowth and mortality were applied to all scenarios. In the case of the French demo, restoration is focusing on the diversification of the maritime pine forests, this is done by planting hedgerows. In the model we created some variations of diversifying the demos' forests.

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 French harvest rule patterns from 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/type (e.g. thinning from below or from above, which emphasis cuttings of different cohorts of the forest stand diameter distribution). In the case of this area a cutting interval of 5 years is used and clear cutting occurs when the quadratic diameter reaches 40. In the baseline scenario no planting is taking place, only natural regeneration. Thinnings happen at a basal area of 25.

2. Restoration scenario #1 Single species oak

In the first restoration scenario, 10% of the plots that were previously dominated by maritime pine are clearcut and then replanted exclusively with oak at a density of 1 500 trees per hectare. The remaining maritime pine plots are also clearcut, but replanted with maritime pine again. The plots that remain maritime pine dominated forest, are managed the same as in BAU.

3. Restoration scenario #2 Single species birch

In the second restoration scenario, 10% of the plots that were previously dominated by maritime pine are clearcut and then replanted exclusively with birch at a density of 1 500 trees per hectare. The remaining maritime pine plots are also clearcut, but replanted with maritime pine again. The plots that remain maritime pine dominated forest, are managed the same as in BAU. No management is happening in the planted birch plots

4. Restoration scenario #3 Mixture maritime pine and oak

In the third restoration scenario, all plots are replanted with a mixture of maritime pine and oak following clearcutting. Oak is planted on 10% of each plot, while maritime pine occupies the remaining 90%. In this case, the planting density for oak is 3 000 trees per ha. The maritime pine is managed similar as in the BAU scenario, while the oak trees remain unharvested.

5. Restoration scenario #4 Mixture maritime pine and birch

In the fourth restoration scenario, all plots are replanted with a mixture of maritime pine and birch following clearcutting. Birch is planted on 10% of each plot, while maritime pine occupies the remaining 90%. In this case, the planting density for birch is 3 000 trees per ha. The maritime pine is managed similarly as in the BAU scenario, while the birch trees remain unharvested.

PROJECTION RESULTS

Growing stock

The development of the growing stock (m^3/ha) over time from 2025 to 2055 is shown in Figure 4. The BAU scenario shows the highest increase in growing stock until around 2038. After 2038 the growing stock flattens towards 2055. In 2025 the growing stock is around 110 m^3/ha and in 2055 the growing stock is around 130 m^3/ha for this scenario. Restoration scenario 1 has the lowest growing stock over the whole simulated period. Restoration scenarios 2, 3 and 4 follow a similar pattern till around 2045 after which scenario 4 flattens off and end similar to the BAU scenario. Scenarios 2 and 3 have the highest growing stock in 2055.

Overall, three of the alternative restoration scenarios result in a higher growing stock (m^3/ha) compared to the BAU scenario, with scenarios 2 and 3 leading to the highest increase by 2055.

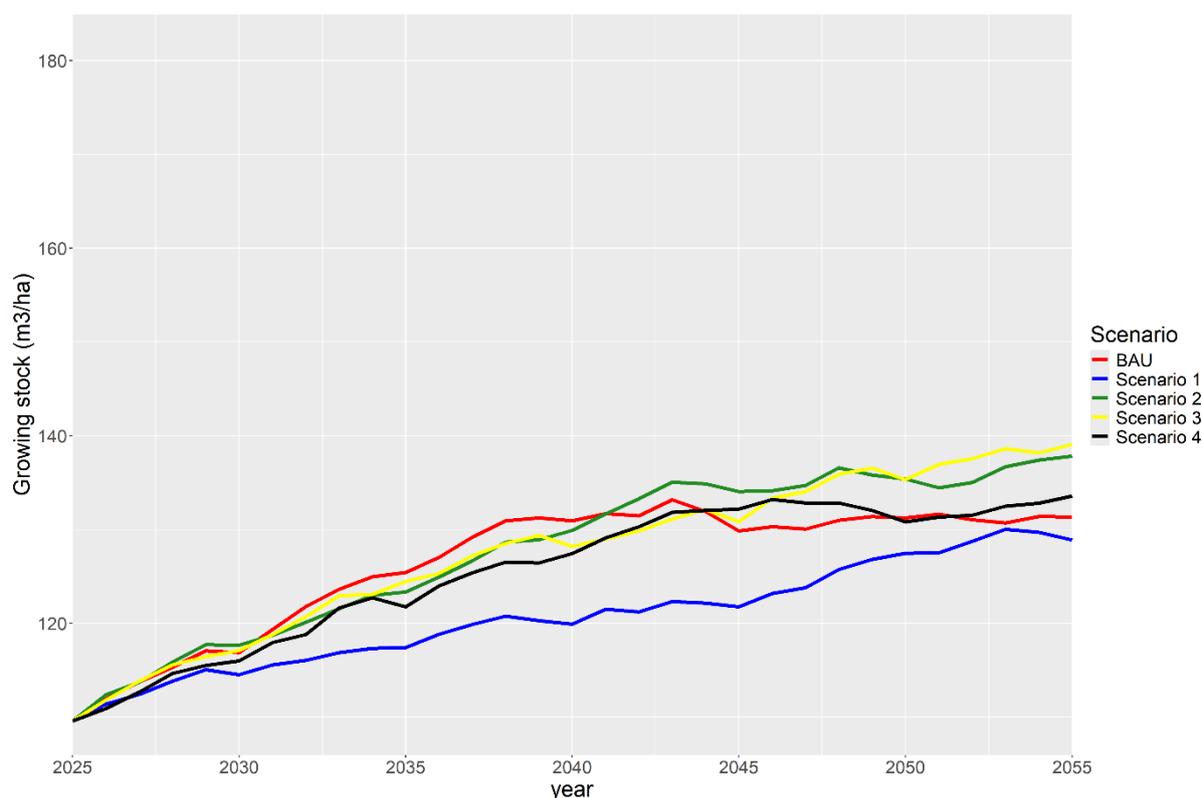


Figure 4. Growing stock (m^3/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2, in yellow Scenario 3 and in black Scenario 4.

Figure 5 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 mostly concentrated in the 20–50 cm diameter classes, especially in the diameter class 30–40 cm. Relatively less growing stock can be found in the larger diameter

classes. The dominant species group is other indigenous *Pinus*, which in this case is mostly *Pinus pinaster*. For all scenarios, in 2055, a shift can be noticed to larger diameter classes, showing tree growth and stand development. In all alternative scenarios more growing stock can be found in the smallest diameter classes, 0–20 cm compared to the BAU scenario. The BAU scenario does not include planting, while the other scenarios include extra planting from either birch or oak.

Pinus pinaster (classified here in the species group other indigenous *Pinus*) remains the dominant species in all scenarios in 2055. However, in the smaller diameter classes *Pinus pinaster* is increasingly complemented by *Quercus* spp, and *Betula*. In scenarios 1 and 3, where *Quercus* is planted, a larger share of this species is found the 10-20 cm diameter class. Similarly, in scenario 2 and scenario 4, *Betula* shows a higher share in the same diameter class. Planting 10% of the area inside the plots after clearcut with *Betula* (scenario 4) or *Quercus* (scenario 3) leads to higher shares of these species in the smaller diameter classes compared to planting 10% of the plots with these species. The number of trees planted per ha is higher in these scenarios.

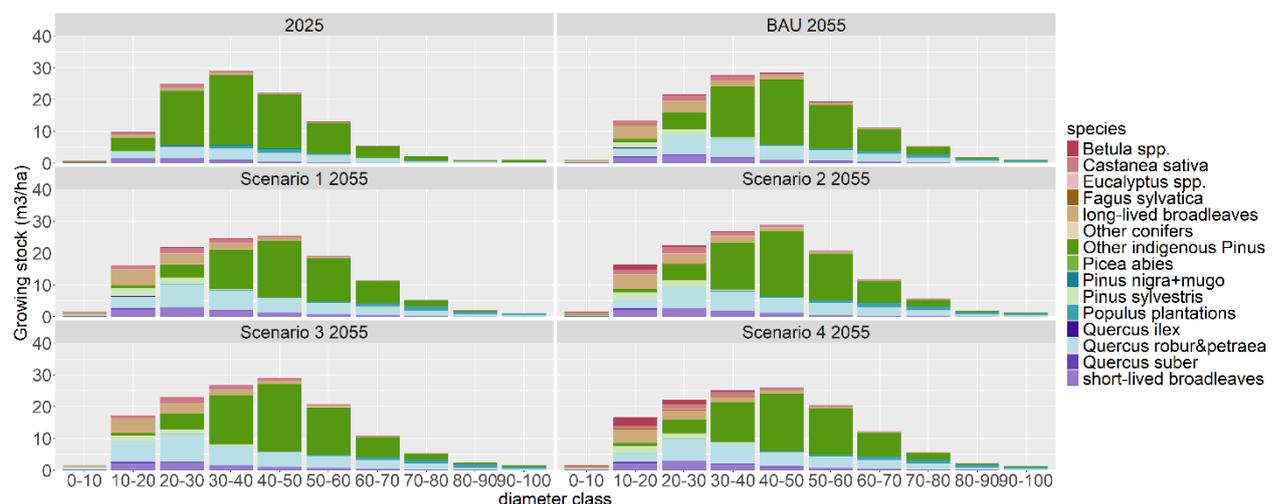


Figure 5. Growing stock (m³/ha) per species and diameter class for the year 2025 and for the different scenarios in 2055

Increment

The gross increment (m³/ha/yr) for the five different scenarios are presented in figure 6. In the first 5 years (2025–2030), all scenarios have an increase in gross increment and after 2030 the increment starts to decline for all scenarios in various ways. BAU (red line) declines steadily with an increment just above 5 m³/ha in 2055. This is the lowest increment of all scenarios.

The alternative scenarios follow a similar pattern for the first 5 years with an increase of increment. Scenario 2 has the highest increment by 2030, slightly below 6.5 m³/ha. After 2030 the increment decreases for all scenarios, with scenario 1 having the fastest decline. Scenarios 1, 2 and 4 stabilize at the end of the simulation around 5.3 m³/ha/yr. The increment of scenarios 1, 2 and 4 is a bit lower by 2055 compared to Scenario 3.

The alternative restoration scenarios result in a higher gross increment compared to the BAU scenario over the whole simulation period, where scenario 3 remains the most productive in the final decade.



Figure 6. 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, in yellow Scenario 3 and in black Scenario 4.

Harvest

Figure 7 shows the harvest (m^3/ha) from 2025 till 2055 for the BAU scenario and the four alternative scenarios. 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.

Scenario 2 and 3 show the lowest harvest over the simulated time period ($4.5 m^3/ha/yr$). The BAU scenario and scenarios 1 and 4 have an average harvest of $4.6 m^3/ha/yr$. These differences are very small.

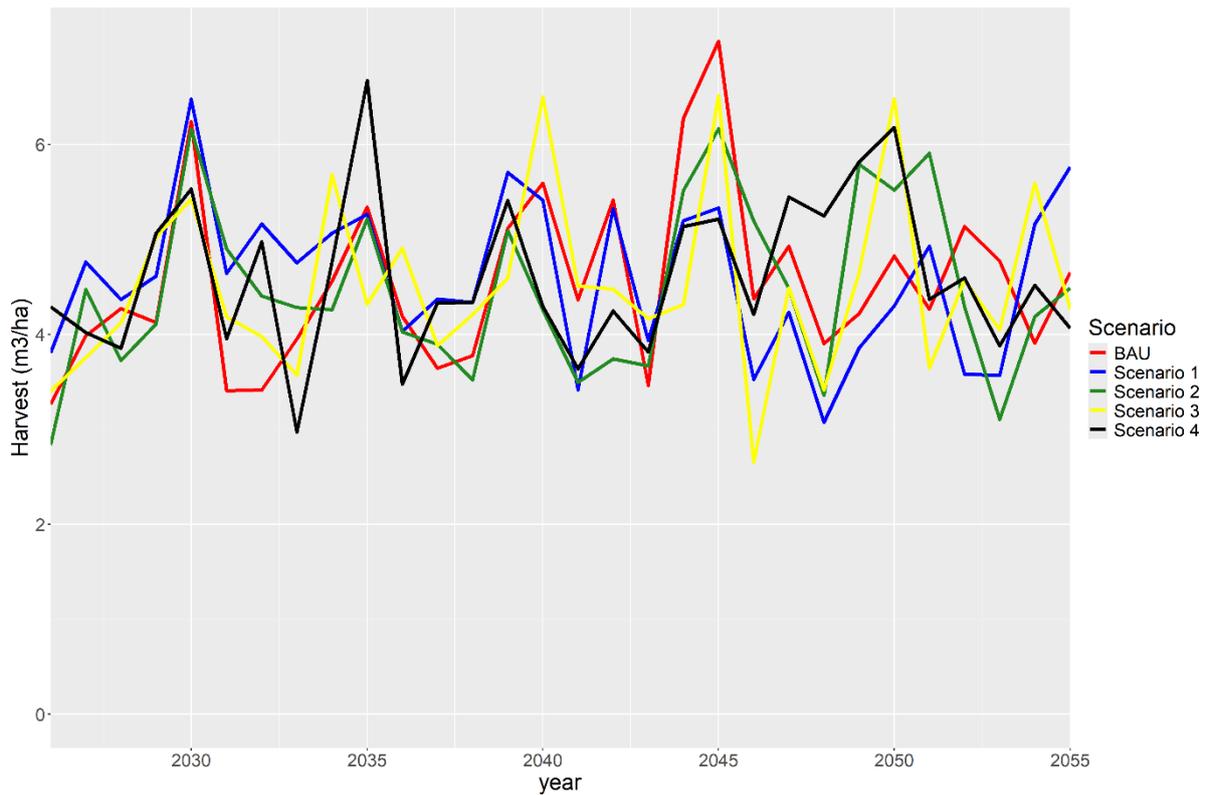


Figure 7. Harvested volume (m^3/ha) development from 2025 till 2055 for the three different scenarios. In red BAU scenario, in blue Scenario 1, in green Scenario 2, in yellow Scenario 3 and in black Scenario 4.

Mortality

Figure 8 presents the average annual mortality ($m^3/ha/yr$) across diameter classes for the five scenarios. No huge differences can be noticed between the BAU scenario and the alternative scenarios. Mortality is mostly concentrated in the diameter classes 20–50 cm, with overall low mortality

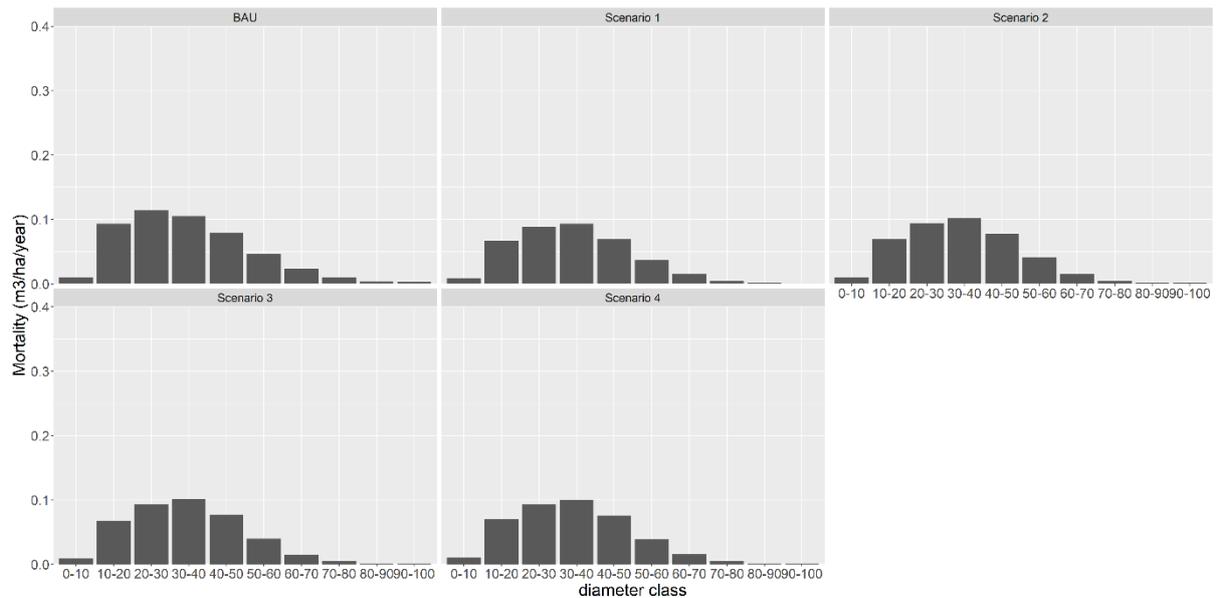


Figure 8. Mean mortality ($m^3/ha/year$) development over diameter classes (cm) for the three different scenarios. Mortality is estimated as the average over the 30-year simulation (from 2025 till 2055).

Gini index

Figure 9 shows the Gini index over time (2025–2055) for the five different scenarios. 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. The BAU (red) scenario, scenario 1 and scenario 2 have a low Gini index during the simulated period, although a slight increase can be noticed. Scenario 3 and scenario 4 have a fast increase in the Gini index which indicates a more structural diverse forest. The index levels off in the last 5 years of the simulated period. The planting of birch and oak inside all the maritime pine plots causes a more diverse structural forest. While in the plots where birch and oak are planted in monocultures, also in this forest little structural diversity can be found in the first 30 years.

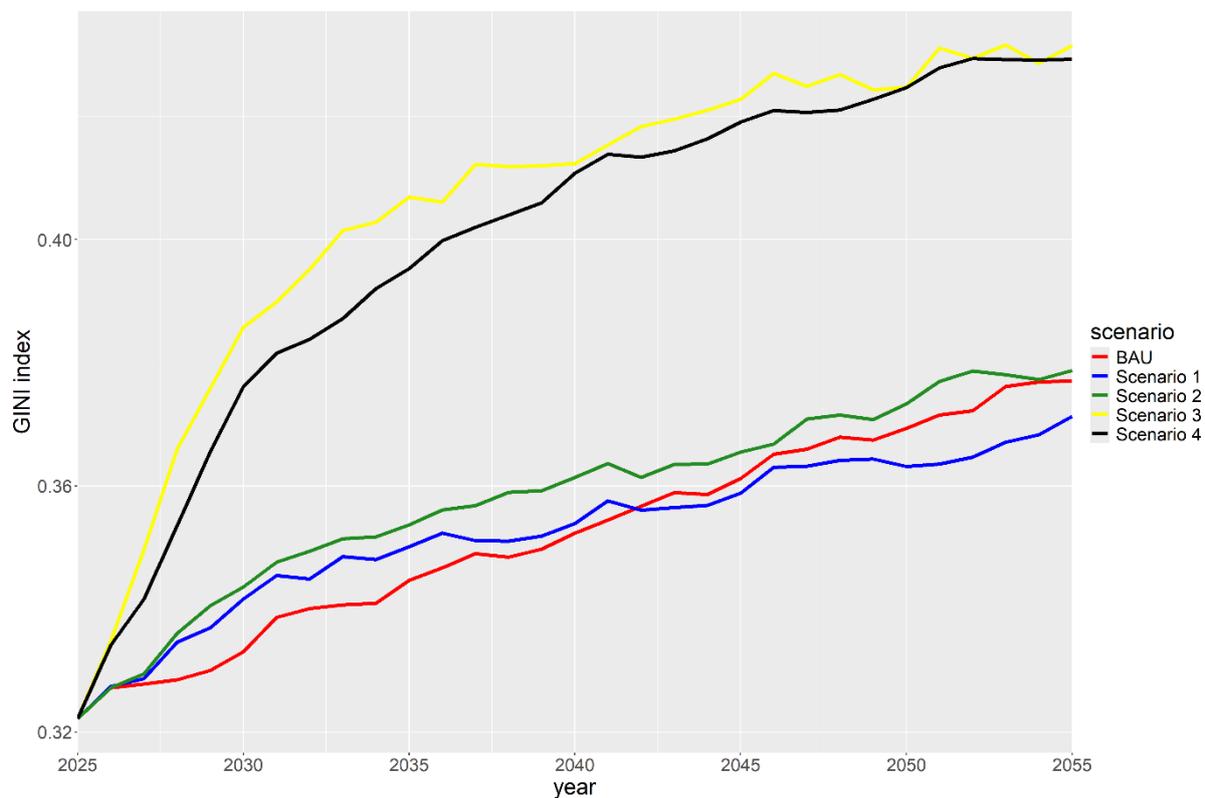


Figure 9 Gini index (inequality index) development for the five different scenarios over time. In red BAU scenario, in blue scenario 1, in green scenario 2, in yellow scenario 3 and in black scenario 4.

Soil organic carbon

Figure 10 shows the development of soil organic carbon stock (SOC) (ton C/ha) over time. Although the SOC is highest under the BAU scenario (red), all three scenarios follow a similar trend. 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 scenarios described resulting in different starting conditions.

Although the SOC is highest under the BAU scenario (red), all four scenarios follow a similar trend. First, all scenarios see an increase in SOC for the first years, after which the SOC stabilizes, with a small increase at the end of the simulation period again.

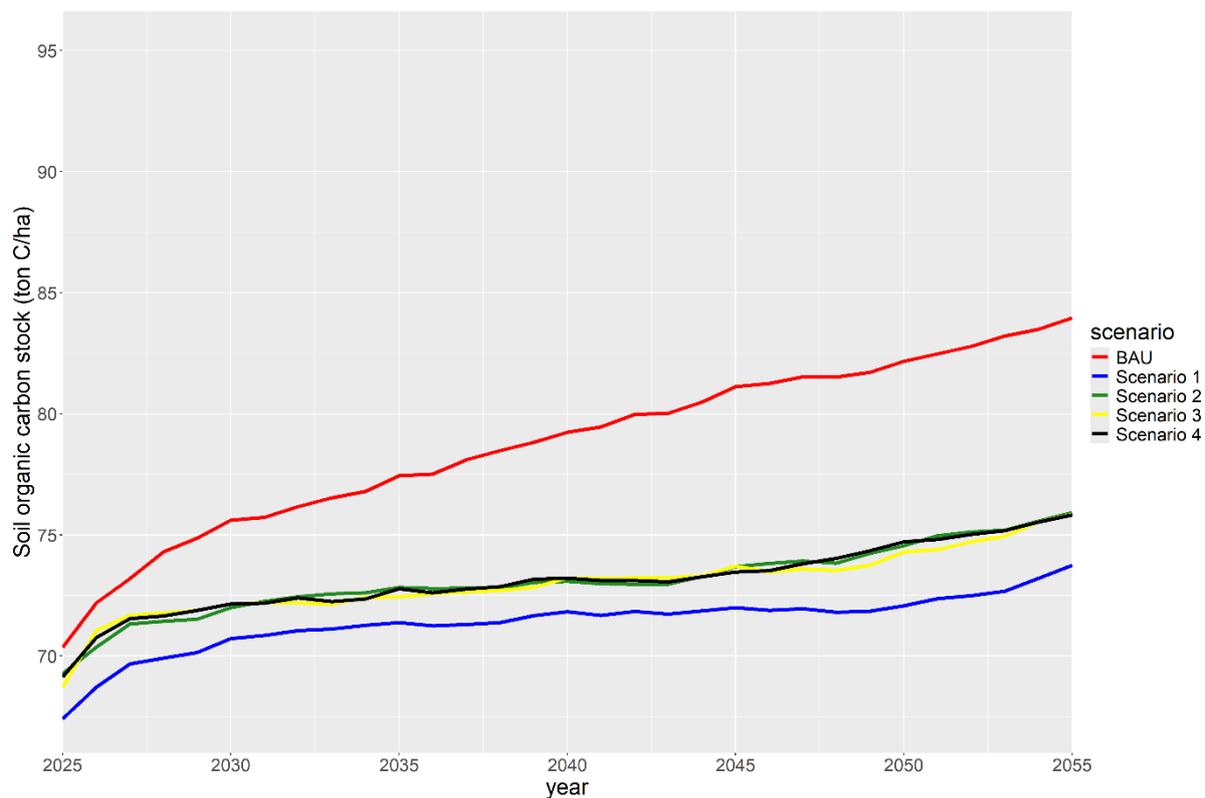


Figure 10. Soil organic carbon (SOC; ton C/ha) development over time for the three different scenarios. In red BAU scenario, in blue scenario 1, in green scenario 2, in yellow scenario 3 and in black scenario 4. The SOC was simulated using Yasso15 model (Järvenpää et al., 2018) coupled with EFISCEN-Space

KEY FINDINGS

Key finding #1

A comparison of the scenarios in the French demo area (867 716 ha of forest) shows that under all alternative scenarios harvest levels can be maintained over the first 30 years after restoration compared to the BAU scenario, while harvest is not happening in the planted broadleaves. Production is an important ecosystem service of these forest and while increasing the species diversity it is not affecting the harvest levels much in the simulations.



The planting costs will be higher the first time after clearcut, due to the higher number of trees planted of birch and oak.

Key finding #2

Across all alternative scenarios, broadleaved species are planted, which will have an impact on biodiversity. The biodiversity advantages of planting broadleaves will continue over time. No management is taking place in the planted broadleaved trees, which means these trees can become old trees in the future with many biodiversity advantages.



In scenario 3 and scenario 4 also the improvement in structural diversity can be noticed with an increased Gini index.

Key finding #3

While the BAU scenario initially shows the highest growing stock, its growth levels off after 2038. By 2055, Scenarios 2 and 3 reach the highest growing stock values. The distribution of growing stock shifts toward larger diameter classes across all scenarios, showing stand development. Restoration scenarios also promote regeneration, with more trees in smaller diameter classes, due to additional planting.



RECOMMENDATIONS

Takeaway #1

More varied forests can be created by planting hedgerows as shown in the scenarios where 10% of maritime pine is monocultures is replaced by birch or oak. This planting, particularly when birch and oak are planted in the maritime pine stands, enhances both the compositional and structural diversity of the forest.



Takeaway #2

Despite lower harvest volumes in some restoration scenarios, differences across scenarios were relatively small. This suggests that improvements in species composition not necessarily require significant reductions in wood production. Adjusting the management and species mixtures can have the advantage of both harvest and more ecological goals.



Takeaway #3

In these monocultures, even small interventions can already enhance both species composition and structural diversity which make the forests more resilient for the future, while harvest levels can be maintained. This creates many biodiversity advantages.



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