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Output 2.1

Deliverable 2.3.3 Pilot Action Report

Version 1

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Purpose and Structure of the Pilot Action Report

This report represents **Output 2.1** ("Jointly developed and implemented Pilot Actions for restoring degraded forests of Central Europe") which is compiled in the form of Pilot Action Report (**Deliverable 2.3.3**) of the RE-ENFORCE project. It documents the jointly developed and implemented Pilot Actions for the restoration of forests affected by various drivers of forest degradation. It synthesizes lessons learned regarding both successes and challenges encountered during the implementation of restoration activities in six Pilot Actions across Central Europe.

The report provides an overview of all pilot areas established within the RE-ENFORCE project and contains six thematic chapters, each addressing a specific type of forest degradation driver tackled in the respective Pilot Actions. Within each thematic chapter, the relevant pilot areas are described in detail, including information on degradation problems, site conditions, implemented restoration measures, and results from scientific and empirical investigations.

As several studies and monitoring activities are still ongoing at the time of writing, some of the results presented in this report should be considered preliminary and may be subject to change. The results presented are intended for internal project reporting and have not yet undergone final scientific validation. Furthermore, the data and results included in this report must not be cited or redistributed without prior permission from the responsible partner organization.

A. Summary

Forest ecosystems across Central Europe are increasingly affected by climate change and related disturbance events such as drought, storms, fires, and pest outbreaks, posing significant challenges for forest restoration and sustainable forest management. The RE-ENFORCE project aims to strengthen knowledge on forest degradation processes and to develop practical approaches for restoring degraded forests under changing climatic conditions.

Within the project, several Pilot Action areas (i.e., forest trial sites for testing restoration measures) were established across Central Europe to investigate different drivers of forest degradation and to test restoration strategies under real management conditions. These transnational Pilot Actions cover a wide range of disturbance drivers, including ash dieback, drought stress, fire, bark beetle outbreaks, storm damage, and inappropriate management of riparian forests. The pilot areas are located in Austria, Croatia, Czech Republic, Germany, Hungary, Italy, and Poland, and are implemented in close cooperation with research institutions, forest managers, and protected area authorities.

Across these sites, a variety of forest restoration strategies for forest restoration are tested, including passive restoration, i.e. natural forest regeneration, and active restoration, including reforestation, assisted species migration, thinning and structural diversification, and the use of biological legacies. Several pilot areas also serve as experimental platforms to test different restoration approaches involving the application of various planting materials, soil preparation methods, and management interventions aimed at improving forest resilience.

Although many of the pilot areas were only recently established, preliminary observations already highlight several important lessons for forest restoration. These include the importance of tree species diversity for increasing forest resilience, the role of biological legacies in supporting natural regeneration, the challenges posed by browsing pressure, and the need to adapt restoration strategies to site-specific conditions and future climatic developments. Long-term monitoring of the pilot areas will provide valuable insights into the effectiveness of different restoration approaches and support the development of climate-adaptive forest management strategies.

Overall, the Pilot Actions implemented within RE-ENFORCE serve as demonstration sites and learning platforms for forest practitioners and stakeholders across Central Europe. The experiences gained from these sites contribute to improving restoration strategies, ultimately to design tailored nature-based solutions to restore forests of Central Europe. These nature-based solutions aim to strengthen the resilience of forest ecosystems in the face of increasing environmental disturbances and facilitating the transfer of knowledge to forest managers and policymakers across Central Europe.

B. Pilot Action Framework

1. Pilot Action Areas

The RE-ENFORCE project implements a set of transnational Pilot Actions to test and demonstrate diverse forest restoration strategies to derive nature-based solutions for the restoration of degraded forest ecosystems in Central Europe. These Pilot Action areas represent diverse ecological conditions, forest types, legal frameworks, and drivers of degradation across the project region. The following sections describe the collaborative framework of the Pilot Actions and provide an overview of their geographical distribution, thematic focus, and participating project partners.

1.1. Transnational Cooperation and Joint Implementation

The degradation of forest ecosystems in Central Europe is driven by factors that extend beyond national boundaries. Major challenges include climate change-induced stress, such as drought, and intensifying disturbances like bark beetle outbreaks, fires, and storms, as well as unsustainable forest management practices, including the widespread establishment of monoculture forest stands. Addressing these challenges requires coordinated transnational approaches and knowledge exchange across countries and forest management systems.

Within the RE-ENFORCE project, six Pilot Actions have been jointly developed and implemented to test for diverse restoration strategies under different ecological and management conditions. These Pilot Actions serve as practical testing grounds for innovative restoration approaches and provide a platform for the exchange of knowledge, experiences, and best practices in forest landscape restoration across Central Europe.

The selection of Pilot Actions was based on a collaborative process and jointly developed and implemented by involving project partners (PPs) and associated partners (APs). The following project partners are involved in the implementation of the Pilot Actions:

- LP Austrian Research Centre for Forests (BFW, Austria)
- PP2 Croatian Forest Research Institute (CFRI, Croatia)
- PP3 Czech University of Life Sciences Prague (CZU, Czech Republic)
- PP4 Landesforst Mecklenburg- Vorpommern (LFOA-MV, Germany)
- PP5 Duna-Dráva National Park Directorate (DDNPD, Hungary)
- PP6 Fertő-Hanság National Park Directorate (FHNPD, Hungary)
- PP7 Forest Research Institute (IBL, Poland)
- PP8 University of Padova (UNIPD, Italy)
- PP9 Slovenian Forestry Institute (SFI, Slovenia)

Key Pilot Action selection criteria included forest type, dominant drivers of degradation, and the relevance of ecosystem services provided by the respective forest ecosystems. The six Pilot Actions implemented within the project are:

- **PA1:** Restoration of European ash forests affected by fungal pathogens in Duna-Dráva National Park (Hungary) and Western Pomerania (Germany).
- **PA2:** Restoration of European beech and Scots pine forests affected by drought and heatwaves in Jastrebarsko (Croatia) and Pilsen (Czech Republic).
- **PA3:** Post-fire regeneration of pine forests in Myszyniec (Poland) and Agordino (Italy).
- **PA4:** Restoration of high-conservation-value riparian forests in Duna-Dráva National Park (Hungary), degraded due to inappropriate management.
- **PA5:** Restoration of Norway spruce forests affected by drought, bark beetle infestation, and climate change in Japons and Horn (Austria).
- **PA6:** Restoration of storm-damaged forests in Toruń (Poland) and Agordino (Italy).

Each Pilot Action tests innovative forest restoration strategies with the ultimate goal to derive tailored nature-based solutions, including adapted tree species and provenance selection, targeted silvicultural management, soil preparation techniques, and elements of assisted migration. The Pilot Actions are embedded in a structured intervention logic linking strategy development, practical testing, and iterative refinement. Strategic forest restoration approaches were translated into Pilot Actions and implemented under real management conditions across Central Europe. Their effectiveness and outcomes were systematically monitored and jointly evaluated through internal and external peer review, including the Joint Evaluation of Pilot Actions (D.2.3.2). The resulting insights are used to refine restoration approaches and to develop transferable solutions that will be directly incorporated into the Transnational Forest Restoration Strategy, transnational guidelines, and the online decision-support system.

The experiences and insights gained from the implementation of the Pilot Actions will contribute to the development of long-term forest management and monitoring approaches. These outcomes will support climate change adaptation and forest landscape restoration strategies and facilitate the transfer of knowledge across the Central European region.

1.2. Overview of the Pilot Actions

The Pilot Actions are implemented within Activity 2.3 of the RE-ENFORCE project. These actions address various forest degradation drivers, habitat types, local legal framework, conservation statuses, and ownership structures. Lessons learned from these Pilot Actions will ultimately be translated into six innovative solutions (Output 3.1) for long-term forest management and monitoring. These solutions will be documented in six transnational guidelines (D.3.1.3) focusing on nature-based solutions for restoring forests affected by ash dieback, drought, bark beetles, fire, storms, and other degradation drivers, incorporating insights from the web-based Decision Support System (D.3.1.2) developed within the project.

The Pilot Action areas are located in seven countries of Central Europe and address several major drivers of forest degradation **(Figure 1 and 2)**.

Pilot Action	Major driver of degradation	Other driver	Main Species	Implementing Partner	Cooperating partner	Location
PA1	Ash dieback - Fungus pathogen		Ash (Fraxinus excelsior)	DDNPD	LFOA + BFW + CZU + FHNPD + all other PPs	Duna-Drava National Park
	Ash dieback - Fungus pathogen		Ash (Fraxinus excelsior)	LFOA	DDNPD + BFW + FHNPD + all other PPs	Western Pomerania
PA2	Drought	Heat waves	Beech	CFRI	CZU + UNIPD + BFW + all other PPs	Jastrebarsko
	Drought	Heat waves	Scots pine	CZU	BFW + IBL + CFRI + all other PPs	Pilsen
PA3	Fire		Scots pine	IBL	UNIPD + all other PPs	Myszyniec DP
	Fire		Black pine, Scots pine	UNIPD	IBL + all other PPs	Agordino, Dolomites, NE Italy (Taibon municipality)
PA4	Improper management of riparian forests		White poplar	DDNPD	FHNPI + all other PPs	Duna Drava National Park
PA5	Spruce Bark Beetle	Drought	Spruce	BFW & AP (Hoyos)	SFI + CZU + all other PPs	Japons, Lower Austria
	Spruce Bark Beetle	Drought	Spruce	BFW & AP (Hoyos)	IBL + all other PPs	Horn, Lower Austria
PA6	Storm		Scots pine, Silver birch, Pedunculate oak	IBL	UNIPD + all other PPs	Torun DP
	Storm		Spruce	UNIPD	IBL + all other PPs	Agordino, Dolomites, NE Italy (Taibon municipality)

Figure 1: Overview of the Pilot Actions including the main driver of forest degradation, the implementing and cooperating partners, and the geographic location.

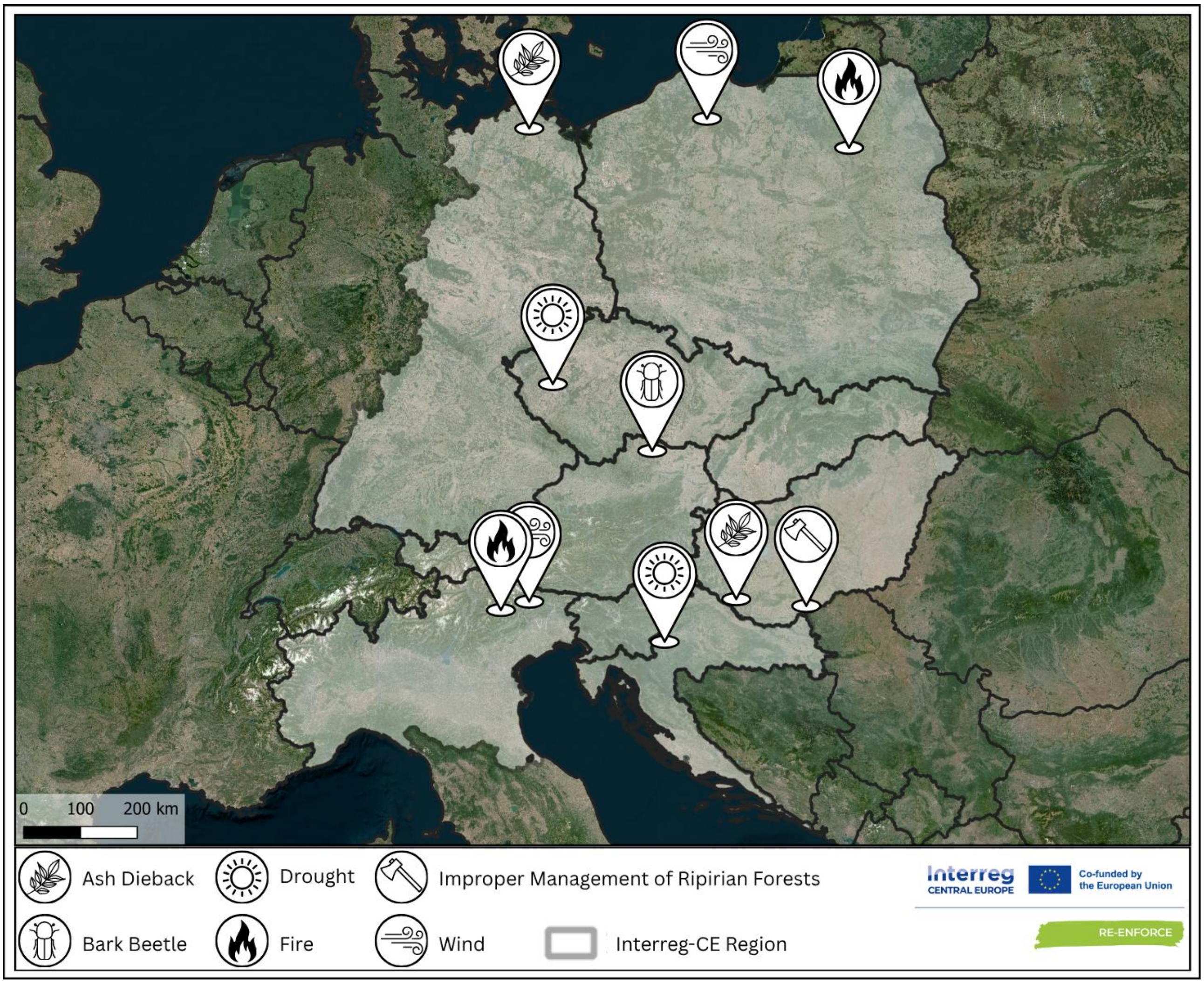

Figure 2: Location of the Pilot Action areas in Central Europe, each dedicated to the respective drivers of forest degradation.

Each implementing partner organization established the required Pilot Actions in cooperation with their APs. Short descriptions of the pilot activities were prepared and disseminated via social media and the organizational channels of the PPs. Drone flights were conducted for all Pilot Action areas to generate high-resolution imagery and 3D models of the forest sites. These models support the web-based visualization of forest structure, species composition, degradation patterns, and implemented nature-based solutions (D.2.4.3). One open day per Pilot Action is planned to engage the general public, raise awareness of forest degradation processes, and present innovative restoration strategies implemented within the project (D.2.4.2).

C. Pilot Actions

2. PA1: Ash dieback

Pilot Action 1 concerns the fungus *Hymenoscyphus fraxineus*, also known as ash dieback disease. The Pilot Action areas for PA1 are located in Hungary and Germany, the implementing partner organizations are DDNPD and LFAO.

2.1. Pilot area in Duna-Dráva National Park, Hungary

Background

Ash dieback has severely impacted the protected hardwood gallery forests along the Drava River in Hungary, creating both economic and conservation challenges. Natural regeneration of these forests is insufficient to replace lost hardwood species, necessitating active conservation measures to establish more resilient ecosystems.

Figure 3: Pilot Action area in Duna-Dráva National Park, Hungary. (picture provided by the DDNPD archive)

Implementation

Management is carried out across seven forestry units, covering approximately 28 hectares. Two Natura 2000 habitats are covered:

- **91F0:** Hardwood riparian forests with *Quercus robur* L., *Ulmus laevis* Pall., *Ulmus minor* Mill., *Fraxinus excelsior* L. or *Fraxinus angustifolia* Vahl. (Ulmenion minoris)
- **91E0:** Alluvial forests with *Alnus glutinosa* (L.) Gaertn. and *Fraxinus excelsior* L. (Alno-Padion, Alnion incanae, Salicion albae)

In *Fraxinus*-dominated hardwood riparian forests, ash dieback led to the death of almost the entire tree stand. Restoration measures aim to establish more diverse hardwood gallery forests through artificial regeneration following clear-cutting and deadwood removal. Approximately 21,000 seedlings (6,800 per hectare) of *Quercus robur* L., *Alnus glutinousa* (L.) Gaertn., *Fraxinus angustifolia* Vahl subsp. *pannonica* Soó & T. Simon, *Betula pendula* Roth, *Ulmus laevis* Pall., *Populus alba* L., *Malus sylvestris* (L.) Mill., and *Pyrus pyraster* (L.) Du Roi were planted. Fencing is required due to high densities of browsing animals.

Figure 4: Fenced area after clear-cutting and artificial regeneration. (picture provided by the DDNPD archive)

In more diverse forests affected by ash dieback, degradation occurs in patches and smaller spots. Here, restoration focuses on supporting natural regeneration, supplemented by planting seedlings of *Quercus robur* L., *Ulmus laevis* Pall., *Betula pendula* Roth, *Fraxinus angustifolia* Vahl subsp. *pannonica* Soó & T. Simon, and *Alnus glutinosa* (L.) Gaertn. Fencing or individual tree protection ensures seedlings are safeguarded from deer browsing.

Investment 2.2 contributes to PA1. Due to the high density of game species (red deer, roe deer, wild boar) in the South Transdanubia region, the protection of newly planted forests or individual trees by fencing or tree shelters is crucial to ensure the long-term success of the restoration measures. Investment 2.2 has been successfully implemented.

Figure 5: Artificial regeneration to support natural regeneration in small patches with tree shelters or fencing. (picture provided by the DDNPD archive)

<u>Preliminary findings</u>

Historically, forest management favored *Fraxinus* over species such as *Quercus*, resulting in nearly homogenous *Fraxinus* forest. The rapid spread of ash dieback caused large-scale mortality, leading to extensive clear-cutting. Larger interventions involving harvesting, planting, and fencing increased costs and extended the time required to re-establish near-natural forest stands.

Conversely, more diverse forests were less affected by the host-specific pathogen. Clear-cuts were applied only to small patches, and natural regeneration was supplemented with planting, leading to lower costs and shorter ecosystem recovery times.

High game densities remain a major threat in these Pilot Action areas, resulting in substantial effort and costs for tree protection.

Future management should prioritize the planting of more resistant species (e.g., *Quercus* instead of *Fraxinus*), while maintaining species diversity to avoid homogenous stands. Additionally, healthy *Fraxinus* forests should be diversified before the fungus causes total infection.

2.2. Pilot area in Western Pomerania, Germany

Background

Since 2002, ash dieback has led to the near-complete decline of European ash (*Fraxinus excelsior* L.) populations across Germany and much of Europe. This is particularly critical in northern Germany, where ash trees thrive on hydromorphic soils that are unsuitable for many other tree species.

Figure 6: Pilot Action area in Western Pomerania, Germany. (© Eric Thurm, LFOA-MV)

Implementation

Experimental plots were established in Western Pomerania on nutrient-rich, permanently or seasonally moist soils. The first symptoms of ash dieback appeared on these sites in 2008. After a storm in 2022, most weakened ash trees were windthrown, leaving only a few individuals of *Fraxinus excelsior* L., often in poor physiological condition.

The management strategy aimed to retain ash trees as long as possible, even after infection with ash dieback. Three experimental areas were developed, each with a distinct management approach:

- **Area I (1.5 ha):** The original plan included fencing and three sub-trails. However, due to funding limitations, the plan was scaled back. The area was neither fenced nor subdivided, deadwood was removed, and natural regeneration is relied upon to re-establish the forest stand.
- **Area II (1.12 ha):** Similar to the modified Area I plan, this area relies solely on natural regeneration. No fencing or planting was conducted, but deadwood remains on the site to support regeneration processes by creating favorable microclimatic conditions.
- **Area III (4.2 ha):** Deadwood was removed, a few seed trees (*Quercus spp*. and *Alnus glutinosa* (L.) Gaertn.) were retained, and remaining crown material was manually arranged in rows. The area was replanted with *Quercus spp*. seedlings and fenced to protect young trees from browsing damage.

Figure 7: Fenced and artificially replanted Pilot Action area (Area III) with remaining seed trees and rows of manually arranged tree remains. (© Eric Thurm, LFOA-MV)

Preliminary findings

A deviation from the original plan for Area I ultimately opened up new opportunities, in line with Polish experience showing that, where *Fraxinus excelsior* L. is no longer present, the introduction of individuals from natural or artificial selection – favoring genotypes less susceptible to ash dieback – may be a suitable option. The adjustment was necessary after it became clear that the existing project framework could not fully support the planned activities, even after efforts to identify complementary resources. These experiences highlight the need for early communication between researchers and practitioners, as well as the importance of long-term monitoring and stable cooperation between research and forest management to ensure continuity of restoration experiments and to generate robust long-term data for adaptive forest management.

Figure 8: Natural regeneration in the Pilot Action area (Area I). (© Anna Wöhlbrandt, LFOA-MV)

The Pilot Action area in Western Pomerania will continue to be monitored over several years to evaluate regeneration, recovery, and persistence of ash trees. Collaboration with other projects (e.g., ResEsche, FraxRecovery, and HydroForMix) will facilitate the upscaling of scientific results for practitioners and project partners across Central Europe.

3. PA2: Drought

Pilot Action 2 concerns drought as the main driver for forest degradation. The Pilot Action areas for PA2 are located in Croatia and Czech Republic, the implementing partner organizations are CFRI and CZU.

3.1. Pilot area in Jastrebarsko, Croatia

Background

European beech (*Fagus sylvatica* L.), a key species in Croatian forests, faces increasing pressure from climate change, particularly from more frequent and prolonged drought events. Drought significantly limits the growth of beech seedlings and potentially leads to reduced survival rates and long-term regeneration challenges in temperate forest ecosystems.

Figure 9: Damage to European beech (*Fagus sylvatica* L.) caused by drought. (© Robert Bogdanić, CFRI)

Implementation

The study investigates how pre-planting drought exposure and nutrient availability influence the resilience of beech saplings. For this purpose, an experimental trial was established near Jastrebarsko to support the restoration of degraded beech forest stands using differently pre-treated seedlings. A total of 768 seedlings were planted at an age of 3+1 years in spring 2022 on an area of 1,200 m². Silvicultural measures included regular annual weeding to control invasive species and competing vegetation. Prior to planting, seedlings were cultivated in containers (18 × 18 × 25.5 cm; volume 6 L). Seedlings exposed to drought and fertilizer treatments prior to planting were compared with seedlings that received regular watering combined with the same fertilizer doses. Seedlings have not been treated since planting. The performance of the seedlings was monitored by differences between four treatment groups:

- **CO:** Control group without pre-planting drought conditions & optimal nutrition
- **CS:** Control group without pre-planting drought conditions & suboptimal nutrition
- **DO:** Pre-planting drought conditions & optimal nutrition
- **DS:** Pre-planting drought conditions & suboptimal nutrition

Monitoring activities included the assessment of mortality and root collar diameter/height and photosynthetic activity (assimilation and gas exchange) measurements.

Investment 2.1 has been successfully procured and contributes to the monitoring activities through the acquisition of an “ADC LCpro T portable photosynthesis system”, enabling in-situ measurements of gas exchange in plant photosynthetic tissues. This equipment supports a more detailed assessment of drought effects on European beech seedlings.

Figure 10: Pilot Action area in Jastrebarsko, Croatia. (© Robert Bogdanić, CFRI)

Preliminary findings

Preliminary results indicate significant differences in root collar diameter between the treatment groups, with nutrient availability showing a strong influence on seedling growth. Seedlings grown under optimal nutrition performed best regardless of whether they were exposed to pre-planting drought treatment or not. In contrast, drought-treated seedlings with suboptimal nutrition exhibited the smallest root collar diameter, indicating that the combination of drought stress and limited nutrient availability represents the most unfavorable conditions for plant growth.

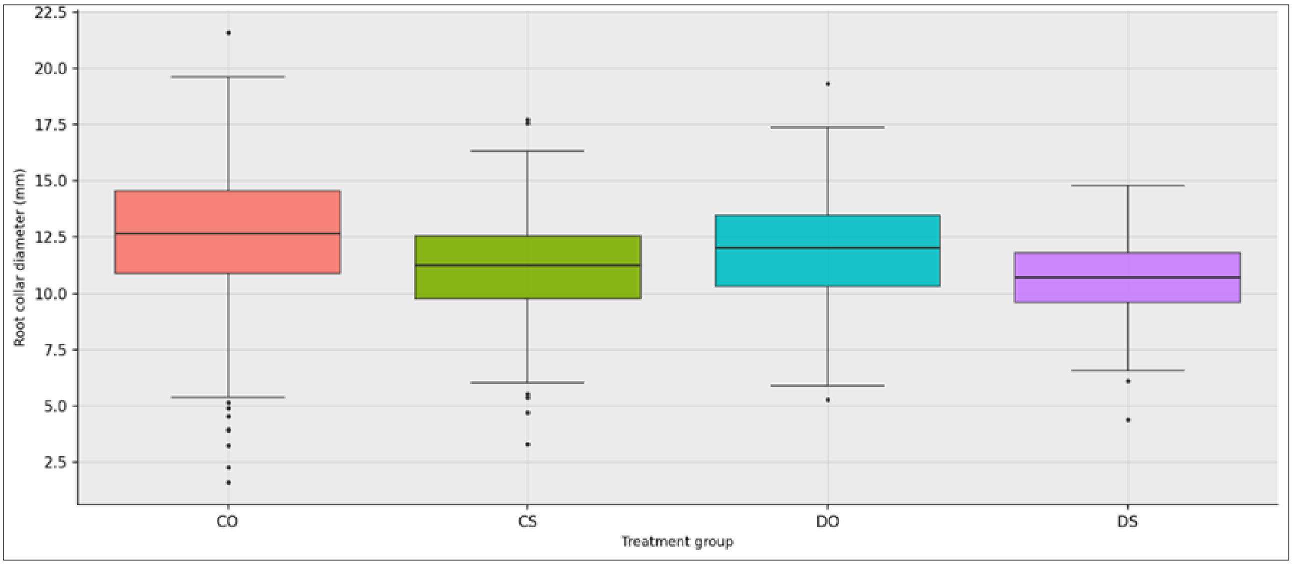

Figure 11: Root collar diameter for four different treatment groups. CO: Control group without pre-planting drought conditions & optimal nutrition, CS: Control group without pre-planting drought conditions & suboptimal nutrition, DO: Pre-planting drought conditions & optimal nutrition, DS: Pre-planting drought conditions & suboptimal nutrition. (© Robert Bogdanić, CFRI)

Photosynthetic activity or stomatal conductance showed no significant differences among the treatment groups, as all surviving seedlings displayed similar assimilation capacities or stomatal regulation.

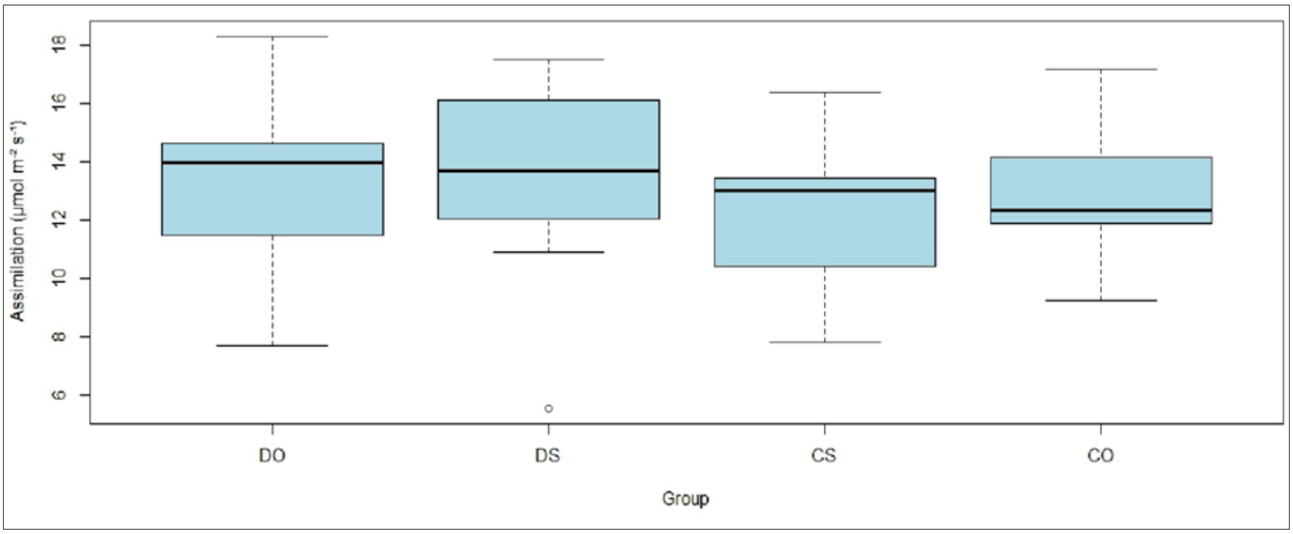

Figure 12: Photosynthetic activity (assimilation) for four different treatment groups. DO: Pre-planting drought conditions & optimal nutrition, DS: Pre-planting drought conditions & suboptimal nutrition, CO: Control group without pre-planting drought conditions & optimal nutrition, CS: Control group without pre-planting drought conditions & suboptimal nutrition. (© Robert Bogdanić, CFRI)

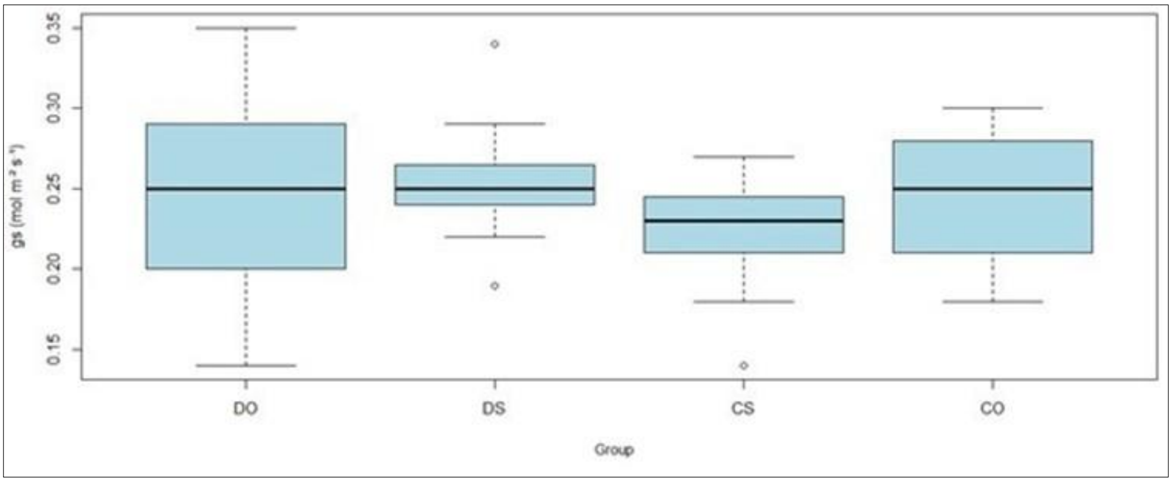

Figure 13: Stomatal conductance for four different treatment groups. DO: Pre-planting drought conditions & optimal nutrition, DS: Pre-planting drought conditions & suboptimal nutrition, CO: Control group without pre-planting drought conditions & optimal nutrition, CS: Control group without pre-planting drought conditions & suboptimal nutrition. (© Robert Bogdanić, CFRI)

Overall, the initial results suggest that adequate nutrient availability during early developmental stages can have beneficial effects on seedling performance and can partially offset the effects of drought. These findings indicate that nutrient availability is a key factor influencing seedling performance under drought conditions.

3.2. Pilot area in Pilsen, Czech Republic

Background

Since 2018, prolonged drought and bark beetle infestations have caused severe degradation of Norway spruce (*Picea abies* (L.) H. Karst) stands near Pilsen, resulting in their significant decline of these forests. To restore ecological balance and maintain economic value, the sustainable recovery of these stands through the establishment of Scots pine (*Pinus sylvestris* L.) and broadleaf species, either in pure or mixed configurations depending on site conditions, is considered a promising restoration strategy.

Figure 14: Pilot Action area in Pilsen, Czech Republic. (© Jan Stejskal, CZU)

Implementation

To test drought legacy effects of Scots pine, controlled drought was applied to two years old seedlings. On the Pilot Action, the drought-treated group as well as a control group of seedlings were planted. Planting material provenance covers two common ecotypes in Czech Republic (lowland and montane) as well as three genetic distinguished origins: Plasy, Třeboň (both lowland), and Děčín from the mountainous region of Czech Republic. In total, 820 individuals were genotyped before planting in spring 2023.

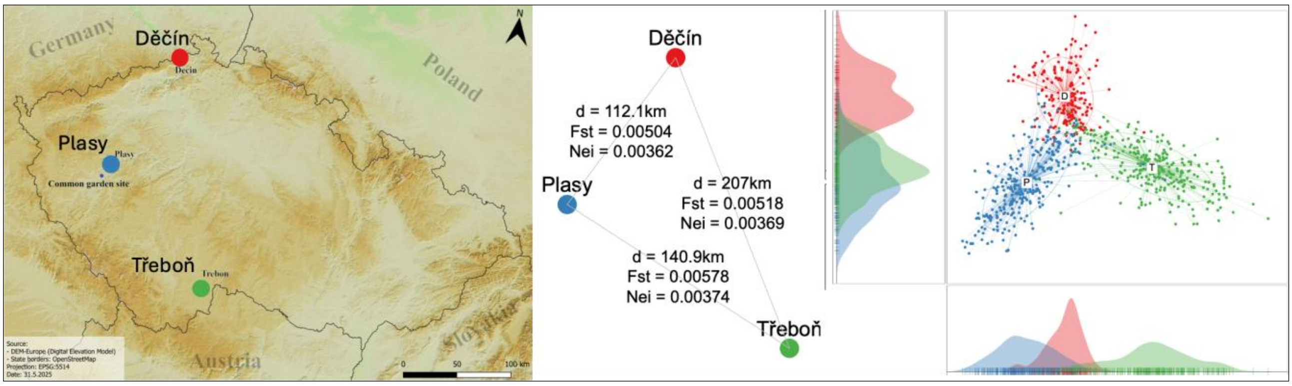

Figure 15: Characteristics of planting material used for the pilot action in Pilsen. Map of provenances (left); geometric and genetic distances (middle, d = Euclidean distance, FST = fixation index, Nei = Nei's genetic distance); DAPC analysis (right; 1st and 2nd components plotted with provenances densities displayed for each component). (© Jaroslav Čepl, CZU)

Continued monitoring of the trail includes:

- **Growth and survival:** Measurement of height, diameter, root collar diameter, overall health, and survival rates.
- **Physiological traits:** Analysis of needle mass per area, fast chlorophyll fluorescence kinetics, photosynthetic pigment content, and VIS-NIR needle reflectance.
- **Geometrical traits:** Creation of 3D models of individual trees to investigate branching angles, stem straightness, and the tendency to form forks.

The objective is to determine whether drought-treated seedlings retain stress memory, potentially influencing their growth and physiological performance, and whether drought responses are linked to long-term field performance relevant for forest restoration, such as long term survival, growth traits or stem form.

Preliminary findings

Initial results indicate that early drought stress is not reflected in survival rates or optical needle properties and shows generally low heritability. After three years, effects of early drought stress are detectable in root collar diameter and needle length, while differences in seedling height have already disappeared. To date, no drought-stress legacy has been observed in optical properties or primary photosynthetic performance.

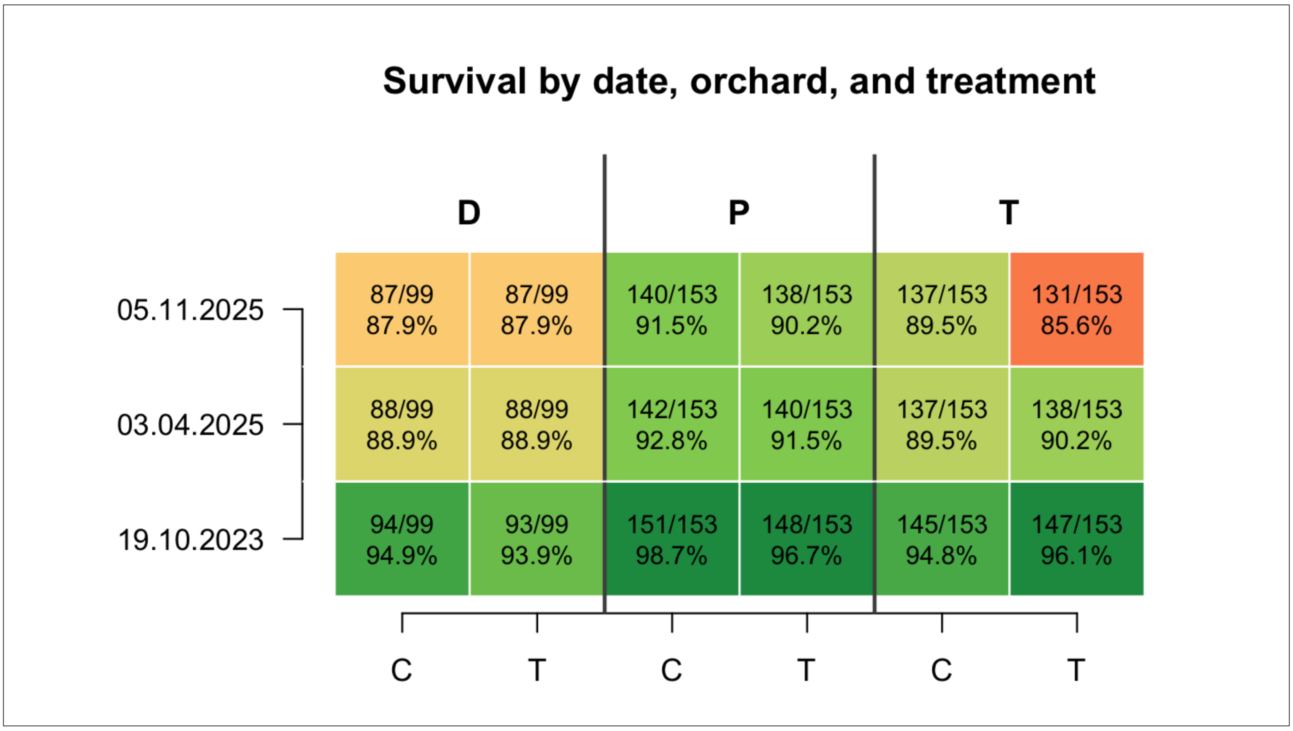

Figure 16: Survival over three monitoring periods of all provenances (D = Děčín, P = Plasy, T = Třeboň), comparing pre-planting drought-stressed seedlings (T) with the control group (C). (© Jaroslav Čepl, CZU)

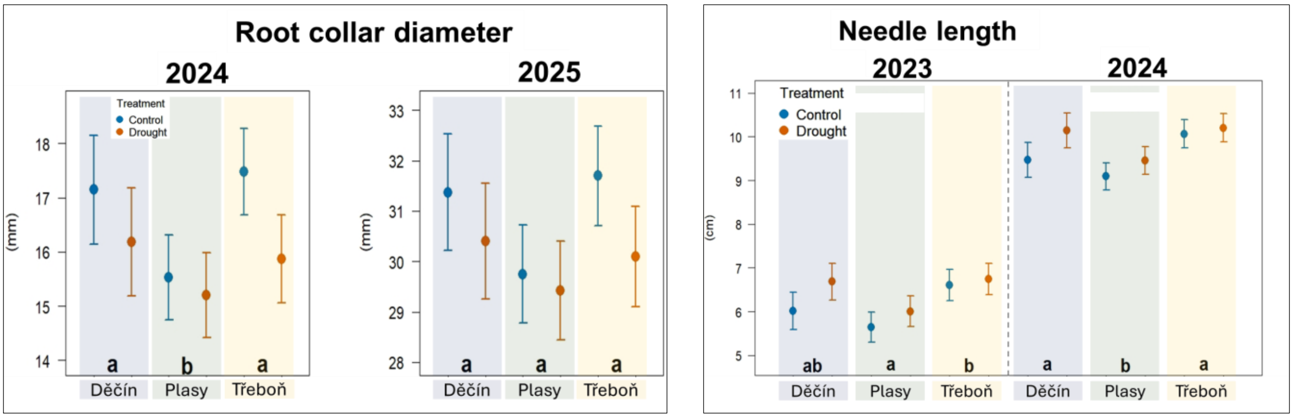

Figure 17: Root collar diameter (left) and needle length (right) of Scots pine provenances from Děčín, Plasy, and Třeboň. (© Jaroslav Čepl, CZU)

In addition, increased bud production on the terminal shoot appears to be a response to induced stress conditions such as drought. To support monitoring of this trait, an automated image-based application for bud counting was developed by CZU.

The preliminary findings suggest that early drought stress during nursery phases may have limited influence on short-term survival and initial field performance of seedlings. However, subtle effects on growth parameters highlight the importance of continued monitoring to assess potential long-term impacts under field conditions.

4. PA3: Fire

Pilot Action 3 addresses forest fires as a major driver of forest degradation. The Pilot Action areas for PA3 are located both in Myszyniec, Poland, and in Agordino, Italy. The implementing partner organizations are IBL and UNIPD, respectively.

Forest fires are traditionally associated with Southern Europe. However, due to climate change, this disturbance is expected to become increasingly relevant in Central European forests. Projections indicate that forest fires may become one of the major disturbance agents in the region in the coming decades, with significant implications for forest management, ecosystem service provision, and the restoration of burnt landscapes.

4.1. Pilot area in Myszyniec, Poland

Background

Poland's forests are predominantly monocultures of Scots pine (*Pinus sylvestris* L.), often relatively young-aged and growing on poor, sandy soils that are highly fire prone. Although forest fires in Poland are typically small (<0.5 ha) due to an effective fire detection and suppression system, approximately 7,000 fires occur annually, posing significant ecological challenges. Climate change is expected to intensify this risk, highlighting the importance of understanding fire as a disturbance and developing strategies for restoring burnt forest areas.

Following a fire in 2014 that affected approximately 100 hectares of Scots pine forest in the Myszyniec Forest District, a study was conducted from 2015 to 2020 to evaluate post-fire adaptation processes. Key results of the study are:

- **Soil Chemistry:** Fire did not significantly alter soil properties across post-fire management methods.
- **Flammability:** The burnt area was non-flammable within one year due to insufficient fuel accumulation.
- **Tree Growth:** Younger pines exhibited increased post-fire growth, while older trees showed reduced growth compared to unburnt controls.
- **Biodiversity:**
    - *Mycorrhizal fungi:* Fire introduced species *Thelephora terrestris* colonized tree roots.
    - *Wildlife:* Saproxylic beetles, small rodents, and woodlark (*Lullula arborea*) densities increased in burnt areas, with no rise in secondary insect pests.

Forest ecosystem recovery after fire is a long-term process that cannot be fully assessed within the timeframe of a single research project. Continued monitoring of the experimental plots is therefore essential to evaluate long-term regeneration dynamics, ecosystem resilience, and the effectiveness of different restoration strategies. Within the RE-ENFORCE project, the experience gathered from research infrastructure and experimental plots established in 2015–2020 are further utilized to generate additional insights into post-fire forest restoration and climate resilience. By capitalising on previous monitoring efforts, the project contributes to the long-term evaluation of restoration approaches and supports the transfer of knowledge to forest managers across Central Europe.


Figure 18: Pilot Action area in Myszyniec, Poland. (© Wojciech Gil, IBL)

Implementation

The Pilot Action area demonstrates results of three different post-fire management scenarios:

- **Standard active forest restoration:** Artificial planting (8,000–10,000 trees per hectare) after ploughing and deadwood removal.
- **Passive forest restoration:** Natural regeneration (i.e., natural succession) without human intervention, serving as a reference.
- **Combined active forest restoration:** A combination of different site preparation and forest regeneration methods (planting, sowing, various planting material and density).

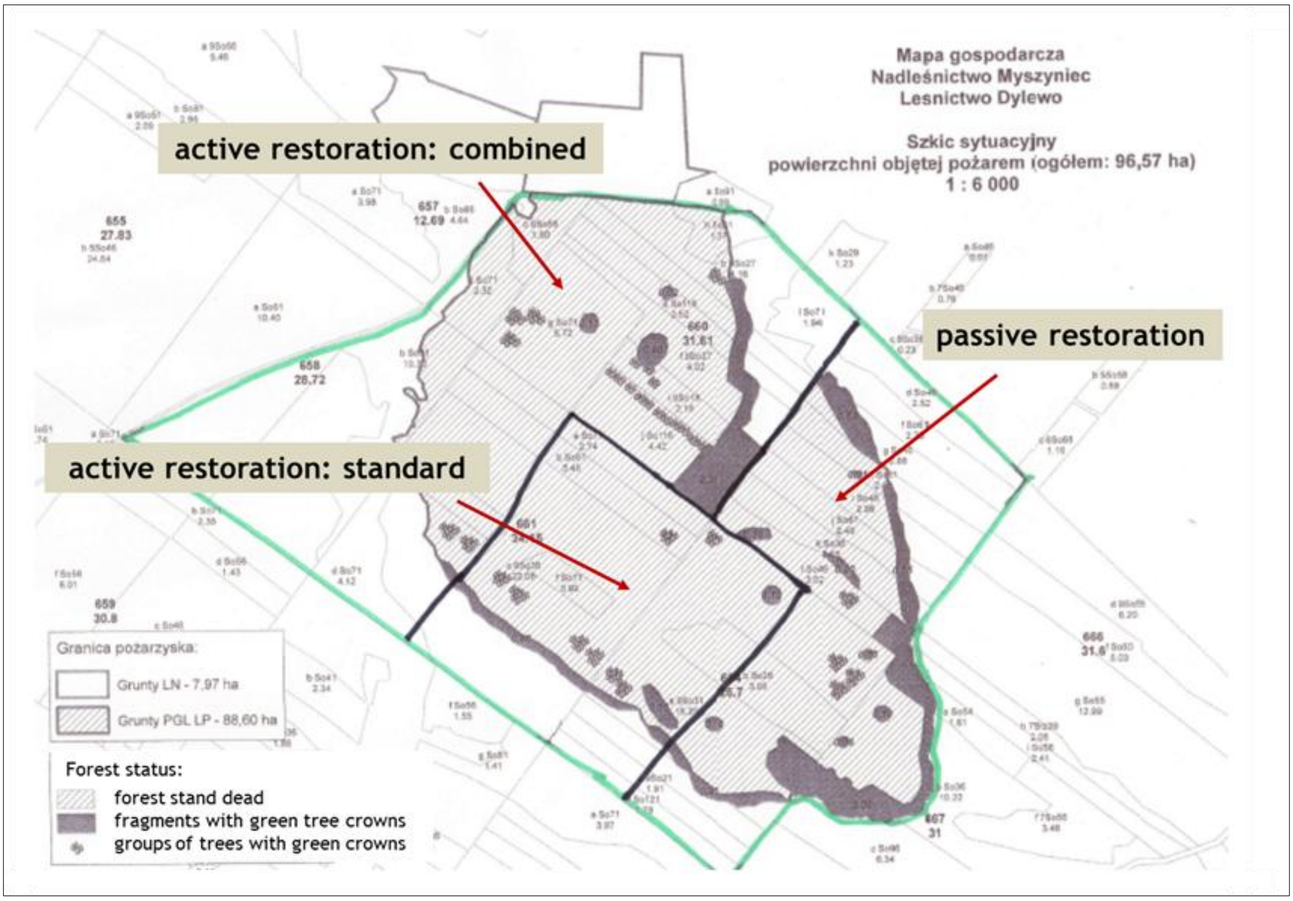

Figure 19: Map of the Pilot Action area in Myszyniec, Poland. Source: Myszyniec Forest District, Polish State Forest Administration, modified.

For the combined active forest restoration method, four site treatments were tested in separate blocks (with four replicates per block):

1. Deadwood removal, chopping, and spreading chips across the site
2. Deadwood removal and ploughing
3. Retaining standing deadwood
4. Leaving deadwood on the ground, arranged in rows

Within these site-treatment blocks, six active restoration techniques were tested:

a) Planting bare-root pine (9,000 trees per hectare)

b) Planting container-grown pine (6,000 trees per hectare)

c) Planting bare root-pine (6,000 trees per hectare) & other species (*Betula pendula* Roth, *Sorbus aucuparia* L.)

d) Sowing pine cones

e) Sowing pine in groups without soil scarification

f) Sowing pine in rows with soil scarification

The Pilot Action evaluates how these three major different management strategies (and further sub-strategies within the combined active restoration scenario) influence post-fire forest restoration, with the aim of promoting ecological complexity and potential co-benefits such as biodiversity conservation.

Figure 20: Examples of different treatment in the combined active restoration scenario. Left: deadwood removal; middle: deadwood removal and chipping; right: leaving deadwood on the ground arranged in rows. (© Wojciech Gil, IBL)

Preliminary findings

Results from the standard active restoration scenario indicate significant abiotic challenges, particularly drought and wind erosion caused by sandy soil conditions. In 2018, these combined factors resulted in a severe failure of some restoration measures. Nevertheless, the active restoration approach currently appears to be generally successful.

Among the treatments tested within the combined active restoration scenario, wood chips from chopped deadwood spread across the site created the most favorable conditions for seedling establishment. Planting generally produced better results than sowing, although drought and wind erosion remained important limiting factors. Container-grown seedlings showed greater height growth compared to bare-root plants, suggesting that container planting may be particularly suitable for restoring fire-damaged sites under these conditions (Gil 2020).

In the passive restoration scenario, successful regeneration of Scots pine and silver birch (*Betula pendula* Roth) was observed, with birch representing the dominant pioneer species. For this taxon, a dynamic tree succession process was observed, with the highest plant density occurring two years after the fire. Besides *Pinus* and *Betula*, other species including *Quercus, Populus, Salix, Juniperus,* and *Frangula* established naturally, resulting in a relatively diverse tree species composition despite the absence of active management (Dobrowolska & Pawlak 2020). However, the invasive species *Prunus serotina* Ehrh. also established within the research area, highlighting potential risks associated with passive restoration and the need for monitoring and possible management interventions to prevent ecological damage.

According to the Polish Forestry Act of 1991, forest cover must generally be restored within five years following disturbance. As a result, passive restoration strategies are rarely applied in Poland. Results from the pilot area in Myszyniec indicate that both active and passive restoration approaches can be successful, although not all tested techniques produced satisfactory outcomes.

Further monitoring is required to evaluate the long-term climate resilience of restoration strategies, the role of biological legacies, impacts on biodiversity, and the overall forest restoration success under different forest management objectives, including timber production, climate resilience, biodiversity conservation, and soil protection.

4.2. Pilot area in Agordino, Italy

Background

The Agordino area, located in the Dolomites (Belluno province, Italy), has been subject to forest fires in the last years due to a combination of climate change, fire-prone vegetation, and steep orography that makes firefighting demanding. In October 2018, a forest fire affected approximately 600 hectares in the municipality of Taibon Agordino. Earlier too, in 2011, a wildfire spread across an area of about 250 hectares over the hamlet of La Muda, causing concerns for safety in the local community, and long-lasting effects on the affected forest. Following these events, several research initiatives were launched to investigate forest recovery processes. Particular attention has been given to both passive restoration through natural regeneration monitoring and active restoration measures that test and compare microsite conditions for post-fire plant establishment.

Figure 21: Post-fire forest regeneration sampling to monitor the efficacy of passive restoration in Italy. (© Flavio Taccaliti, UNIPD)

Implementation

Forest recovery through natural regeneration after fire is influenced by several factors, including fire severity, pre-fire stand conditions, micro-environmental factors – such as ground cover – and the structure of surrounding forests. To better understand these processes, field data on post-fire forest regeneration are collected, with a particular focus on topographical and microclimatic parameters.

In addition, a small-scale restoration trial has been established to investigate active restoration approaches for burnt forests in mountainous environments. The objectives are to test nature-based solutions and assisted species migration as potential restoration strategies, and to derive management recommendations for post-fire forest restoration tailored to the ecological conditions of the region. This active restoration experiment was established in 2025 on six experimental plots of approximately 50 m^2 each. The trial uses seedlings of downy oak (*Quercus pubescens* Willd.) to test the potential benefits of biological legacies – such as deadwood pieces and pioneer shrubs – for supporting artificially planted seedlings after fire disturbances. These structures are considered promising nature-based solutions, as they can create favorable micro-environmental conditions that promote seedling establishment and growth.

Figure 22: Experimental plots of artificial regeneration using *Quercus pubescens* Willd. (© Flavio Taccaliti, UNIPD)

The experiment also explores the potential role of assisted species migration. Downy oak is currently not present in the study area but occurs further south and in comparable burnt sites in the Western Alps. The trial therefore represents one of the first experimental applications of assisted migration in Veneto and contributes to ongoing discussions among forest managers and stakeholders regarding climate-adaptive forest restoration strategies.

Monitoring of seedling survival and height growth will be conducted in the coming years to assess the influence of biological legacies and microsite conditions on post-fire restoration success.

Preliminary findings

As the active restoration experiment was established only in late 2025, no preliminary results from the assisted migration trial are available yet. However, observations of passive restoration processes in the burnt area indicate that natural regeneration is occurring successfully in many locations, with time since the disturbance appears to be a key driver of regeneration success. The regenerating species are largely adapted to the current climatic conditions of the region. While passive restoration can support ecosystem recovery, it may not facilitate economic recovery quickly enough or enable the shifts in species composition that may be required to cope with rapidly changing climatic conditions.

In this context, the ongoing experiment on assisted species migration aims to assess whether the introduction of tree species with higher tolerance to drought and certain fire regimes may enhance long-term forest resilience. The results are expected to provide important insights into how active restoration measures can complement natural regeneration processes and support climate-adaptive forest management in fire-prone mountain landscapes.

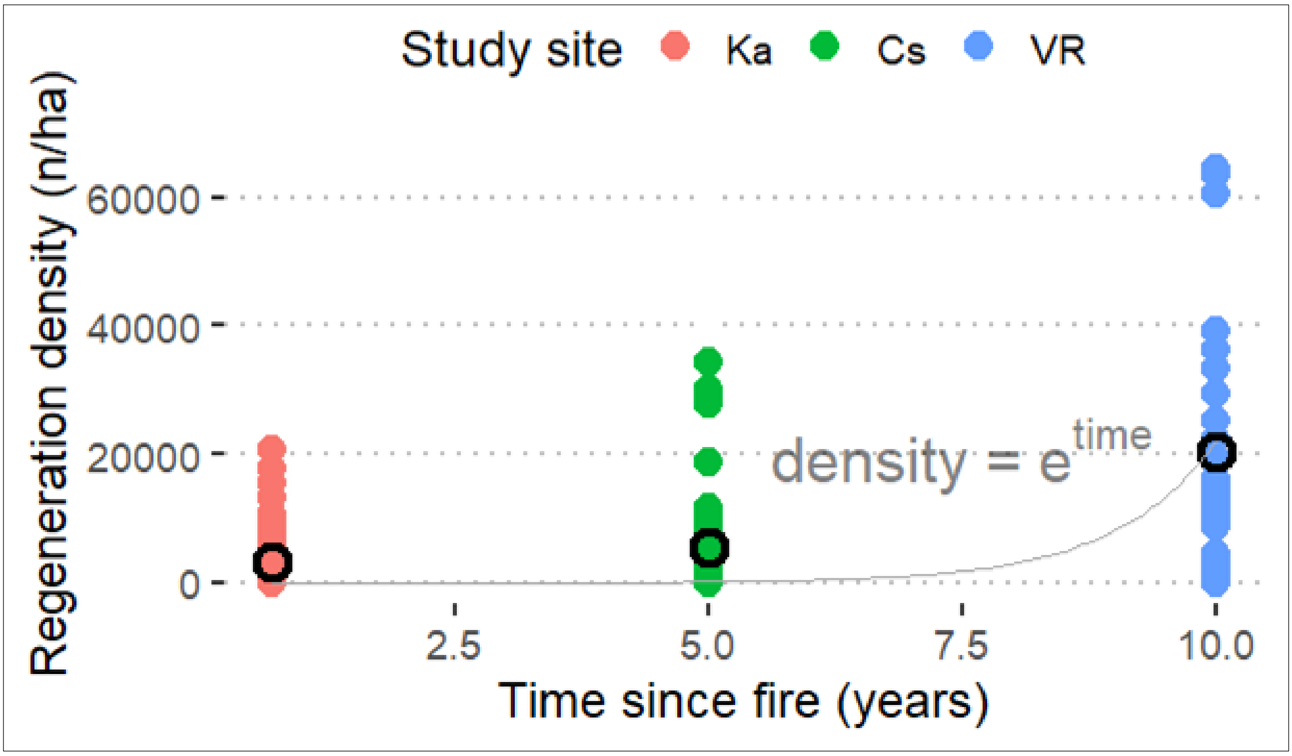

Figure 23: Preliminary results on the density of agamic regeneration per plot in black pine (*Pinus nigra* J. F. Arnold) burnt forests (Taccaliti, 2025). Black points indicate the mean values.

5. PA4: Improper management of riparian forests

Pilot Action 4 addresses improper management as a driver of degradation in riparian forests. The Pilot Action area for PA4 is located in Hungary, the implementing partner organization is DDNPD.

5.1. Pilot area in Duna-Dráva National Park, Hungary

Background

Prior to the establishment of the Duna-Dráva National Park Directorate, forest management on the Danube floodplain prioritized economic objectives. Although often native species were used for reforestation, the resulting white poplar (*Populus alba* L.) and hybrid poplar plantations lacked age, structural, and species diversity. The dense primary canopy limits light availability, preventing the development of a secondary canopy and inhibiting the natural regeneration of other tree species.

Figure 24: Pilot Action area in Duna-Dráva National Park, Hungary. (picture provided by the DDNPD archive)

Implementation

To enhance species diversity in formerly managed *Populus alba* L.-dominated forests, two forest stands are targeted within the project. The first stand (2.2 ha) represents the Natura 2000 habitat 91E0 – Alluvial forests with *Alnus glutinosa* (L.) Gaertn. and *Fraxinus excelsior* L. (Alno-Padion, Alnion incanae, Salicion albae), including hardwood species such as *Quercus robur* L. and *Fraxinus angustifolia* Vahl subsp. *pannonica* Soó & T. Simon. The second stand (4.4 ha) is currently not classified as a Natura 2000 habitat due to changes in species composition and the dominance of hybrid poplar.

The restoration objective is to establish species-rich softwood gallery forests through several management measures:

- Removal of hybrid poplar and invasive species such as *Acer negundo* L.
- Thinning of dense *Populus alba* L. stands
- Promoting natural regeneration and supporting it through targeted planting of native tree species (e.g., *Ulmus laevis* Pall., *Quercus robur* L., *Fraxinus angustifolia* Vahl)

Within the Pilot Action area, almost all hybrid poplar and invasive species individuals have been removed. In *Populus alba* L.-dominated forests, canopy openings are created through selective cutting and thinning, allowing more light to reach the forest floor. These openings particularly focus on areas where natural regeneration of other species is already present. Additional hardwood species, such as *Quercus robur* L. and *Ulmus laevis* Pall., will be planted to further increase species diversity.

Figure 25: Pilot Action area after hybrid poplar removal. (picture provided by the DDNPD archive)

Prior to planting, preparatory steps such as soil sampling and the preparation of a forest management plan are required. In addition, official permissions from forestry and nature conservation authorities must be obtained due to the strict Hungarian forestry legislation and the protected status of the area.

Due to the high density of game species (red deer, roe deer, wild boar) in the South Transdanubia region, protection of newly planted trees is essential. Fencing will therefore be implemented to prevent browsing damage and ensure the long-term success of restoration measures. Investment 2.3 contributes to the implementation of PA4 and is expected to be carried out – together with the planting activities – within the current reporting period (spring 2026).

Preliminary findings

Only a small proportion of softwood gallery forests in the region currently exhibit a natural species composition – even within the protected areas – as most stands are strongly influenced by white poplar and hybrid poplar plantations. Due to insufficient follow-up management (e.g., lack of thinning) and limited consideration of species mixtures, many stands have developed into dense and structurally homogeneous forests. Fast-growing softwood species often outcompete other native species under these conditions.

Common forest management practice typically involves thinning *Populus* stands by 10–15% of stand volume. Preliminary observations suggest that this intensity is insufficient to achieve the restoration objective of more diverse and structurally complex gallery forests. To promote natural regeneration of native species and support the survival of planted seedlings, more intensive thinning (up to 40–50%) appears necessary to create favorable light conditions for young trees.

Figure 26: Pilot Action area after heavy thinning, designated for artificial and natural regeneration. (picture provided by the DDNPD archive)

Furthermore, shifts in site conditions have been observed in many areas. Former moist or wet soils – originally characteristic of softwood gallery forest habitats – have become drier due to declining groundwater levels. This groundwater loss may lead to less suitable conditions for typical softwood species, while potentially favoring hardwood species such as *Quercus robur* L. or *Fraxinus angustifolia* Vahl. These changing site conditions were therefore considered when planning the active restoration measures in order to establish more climate-resilient forest stands.

In addition, forest restoration in these ecosystems often requires active management interventions. Demonstration sites are therefore important to illustrate the long-term effects of different management approaches. The Pilot Action area will serve as a long-term demonstration and training site for practitioners, showcasing restoration strategies for softwood riparian forests in the Duna-Dráva region and facilitating the transfer and upscaling of these approaches to comparable riparian forests across Central Europe.

6. PA5: Spruce bark beetle

Pilot Action 5 concerns spruce bark beetle outbreaks as a driver of forest degradation. The Pilot Action areas for PA5 are located in Austria, the implementing partner organization is BFW.

6.1. Pilot area in Japons and Horn, Austria

Background

Hoyos Estate and Forest Management Company (Horn), spanning 2,800 hectares of forest and additional agricultural land in Austria and the Czech Republic, has faced severe challenges due to climate change. Since 1961, a temperature increase of over 2°C has caused prolonged droughts, weakening forest stands and leading to insect infestations, particularly bark beetles. This has resulted in significant economic losses and threatens the sustainability of forest management in the region.

Figure 27: Pilot Action area in Japons, Austria. (© Stefan Ebner, BFW)

Implementation

To address these challenges, different strategies were implemented to restore forests following bark beetle outbreaks in Japons and Horn. The main restoration strategy is transitioning former pure conifer stands to mixed deciduous forests with resilient species such as oak (*Quercus spp.*) and Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco). This transition will be accompanied by several actions such as:

- Establishing seed orchards to ensure a steady seed supply for future reforestation.
- Testing different planting densities and spacings schemes while considering mechanized tending operations
- Reducing the use of chemicals while enhancing reforestation techniques, including mulching, soil preparation, and precise planting.
- Intensifying hunting to mitigate damage from game browsing.

The Pilot Action comprises three forest plots that were severely affected by bark beetle infestations, leading to the degradation of formerly conifer-dominated stands. All plots were subsequently restored through reforestation with climate-resilient, mixed deciduous tree species, primarily oak (*Quercus spp.*), complemented by minor admixtures of hornbeam (*Carpinus betulus* L.), small-leaved lime (*Tilia cordata* Mill.), and scattered conifers (*Picea abies* (L.) H. Karst, *Pseudotsuga menziesii* (Mirbel) Franco). Prior to reforestation, all areas were mulched as a soil preparation measure to improve planting conditions, reduce competing vegetation, and enable mechanical maintenance such as mowing.

The plots differ in size, planting density, stand age, and maintenance intensity, allowing for a comparative assessment of different reforestation and management approaches. Across all sites, systematic tending measures – mainly repeated mowing – were applied over several years to secure establishment success and reduce early-stage competition. In some areas, fencing was installed to protect young trees from game browsing, and limited chemical plant protection was applied where necessary **(Table 1)**.

Table 1: Overview of the different Pilot Action stands in Japons and Horn.

Plot	Previous Stand	Reforested Area	Stand Age	Planting Spacing	Maintenance Measures	Tree Species Composition
1	100% Norway spruce, approx. 80 years	4.5 ha	8 years	1.5 × 1.5 m	Mulching before planting, Mowing twice per year for 4 years, Fencing on 4.5 ha area	90% Oak 5% Hornbeam 5% Small-leaved lime Scattered Norway spruce
		0.5 ha	12 years	2.0 × 2.5 m		
		Remaining area	6 years	2.0 × 1.25 m		
2	90% Norway spruce, 10% Scots pine, approx. 70 years	15 ha	6 years	2.0 × 1.25 m	Mulching before planting, 11 ha: mowing twice per year for 4 years, 4 ha: ongoing maintenance, one chemical treatment and one mowing per year	90% Oak 5% Hornbeam 5% Small-leaved lime Scattered Norway spruce and Douglas fir
3	95% Norway spruce, 5% Scots pine, approx. 75 years	3.1 ha	6 years	1.5 × 1.5 m	Mulching before planting, Mowing twice per year for 4 years	90% Oak 5% Hornbeam 5% Small-leaved lime Scattered Norway spruce
		Remaining area		2.0 × 1.25 m		

Preliminary findings

Planting spacing was intentionally chosen to be relatively dense due to the risk of early mortality caused by browsing pressure, late frost, and drought. Initial observations indicate moderate to high mortality caused by these factors, suggesting that relatively high planting densities may be necessary to ensure the successful establishment of mixed deciduous forests in this region.

In addition to ecological restoration objectives, the Pilot Action also aims to establish economically viable forest stands capable of producing high-quality timber under changing climatic conditions. Species selection, planting design, and future silvicultural interventions therefore consider both climate resilience and the long-term economic sustainability of forest management.

Tending measures are primarily applied mechanically, and planting spacing was designed to allow the use of mechanized maintenance operations. During the first years after planting, two tending interventions per year are required to reduce competition from ground vegetation. The overall objective is to avoid chemical treatments as far as possible. However, in one area weed competition proved too strong to be controlled mechanically alone, and chemical plant protection was therefore applied carefully and only where necessary to ensure the survival of young trees.

Figure 28: Pilot Action area in Japons after mechanical mowing. (© Francesco Atzeni, UNIPD)

Early silvicultural interventions will likely be required in the near future to guide the development of these young deciduous mixed stands. Additional experiments on other sites are ongoing to gain further experience with suitable management approaches that may later be applied to the Pilot Action areas.

Browsing damage represents another major challenge in the Pilot Action area. Communication between the forest owner and the regional authorities responsible for hunting management has been constructive. Adaptations to the hunting regime, including an extension of the hunting season and increased hunting quotas, were implemented to support forest restoration with climate-resilient tree species. Despite these measures, browsing pressure remains a significant challenge. Empirical observations suggest that without adapted game management, successful forest regeneration would hardly be possible – even when fencing is applied.

Some of the restoration measures were initiated before the start of the RE-ENFORCE project. Within the project, the Pilot Action contributes primarily through continued monitoring, evaluation of management approaches, and the documentation of long-term stand development. This monitoring is essential to assess whether the applied restoration strategies will successfully lead to climate-resilient and economically valuable forest stands. In this context, the pilot area serves as an important demonstration site for practitioners in the region, illustrating how forests affected by bark beetle outbreaks can be restored while maintaining the potential for sustainable timber production under changing climatic conditions.

7. PA6: Storm

Pilot Action 6 addresses storm and windthrow as the main driver for forest degradation. The Pilot Action areas for PA6 are located in Italy and Poland, the implementing partner organizations are UNIPD and IBL, respectively.

7.1. Pilot area in Toruń, Poland

Background

In August 2017, a powerful hurricane struck northern Poland, causing widespread damage to forest ecosystems, affecting over 40,000 hectares of forest. This event represents the largest windthrow in the history of Polish forestry. The most severely impacted areas were the forest districts of the Regional Directorate of State Forests in Toruń, which lost 18,425 hectares of forest. In 2022, an initiative was launched to explore effective restoration strategies for windthrown areas and minimize risks associated with large-scale reforestation.

Figure 29: Pilot Action area in Toruń, Poland. (picture provided by the Polish State Forest archive)

Implementation

To investigate forest restoration and regeneration methods, a series of experimental plots was established. The plots are located on both poorer sites (fresh coniferous forest habitats typically dominated by pine or birch) and richer sites (fresh forest habitats more suitable for oak and other broadleaved species).

To assess the influence of seedling type (bare-root, container) and planting season on restoration success, Scots pine (*Pinus sylvestris* L.) was planted in 30 × 30 m blocks without fencing using four treatments:

- Bare-root seedlings planted in autumn 2022
- Bare-root seedlings planted in spring 2023
- Container-grown seedlings planted in autumn 2022
- Container-grown seedlings planted in spring 2023

In addition, a planting experiment with pedunculate oak (*Quercus robur* L.) was established to investigate the influence of seedling age, soil preparation techniques, and planting method on the restoration of windthrown Scots pine forests on poor sandy soils using broadleaved species. Experimental plots in the Runowo Forest District compare:

- 1-year-old vs. 3-year-old oak seedlings
- Ploughing vs. no site preparation
- Mechanized vs. manual planting

Following the establishment of artificial regeneration, tending measures are required to secure plant survival and guide stand development. The project therefore investigates different tending intensities of naturally regenerating broadleaved species – mainly birch (*Betula pendula* Roth) and aspen (*Populus tremula* L.) – within young Scots pine plantations. For this purpose, 50 × 50 m experimental plots were established with the following treatments:

- Removal of all broadleaves
- Retention of 20 broadleaved individuals per hectare
- Retention of 100 broadleaved individuals per hectare
- Retention of all broadleaves (control plot)

Figure 30: Experimental plot testing different tending intensities of naturally regenerating broadleaved species. (© Stefan Ebner, BFW)

Long-term monitoring of these experimental plots will support the development of evidence-based restoration strategies for wind-disturbed forests in the region. In particular, the Pilot Action aims to identify suitable post-windthrow regeneration approaches regarding:

- Optimal tree species composition for successful forest restoration
- Effective soil preparation techniques
- Suitable seedling characteristics (age and type)
- Appropriate intensity of tending interventions

Preliminary findings

Initial results from the Scots pine planting experiment indicate that container-grown seedlings perform better than bare-root seedlings in terms of early establishment success. The influence of planting season appears to be relatively limited, suggesting that seedling quality and pre-planting conditions have a stronger influence on early growth performance than planting timing.

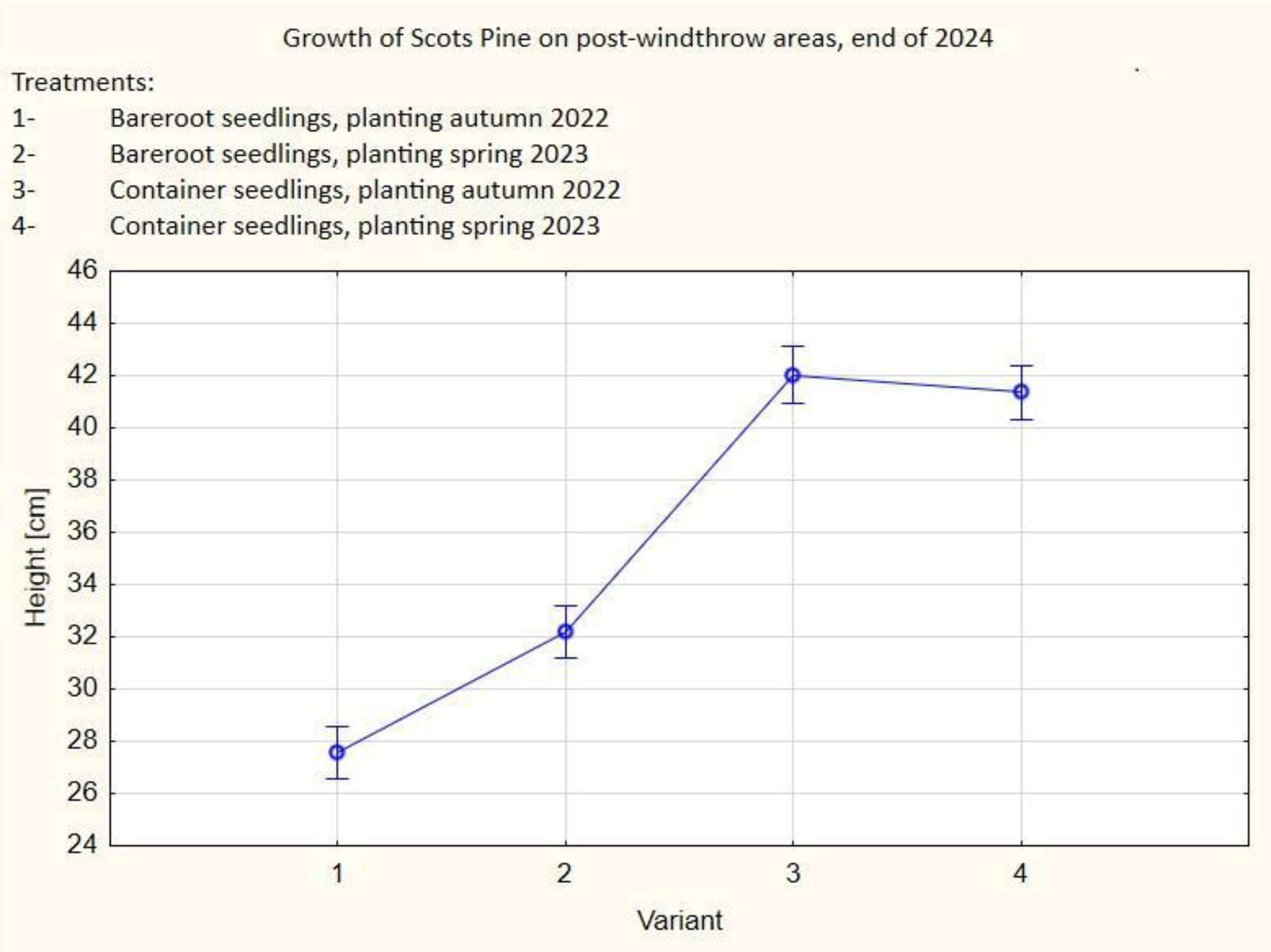

Figure 31: Preliminary results on the influence of seedling type and planting season on the growth of Scots pine. (© Jan Łukaszewicz, IBL)

However, most experimental plots were established recently, and comprehensive conclusions cannot yet be drawn. Continued long-term monitoring will therefore be essential to evaluate the effects of the different treatments on stand development, regeneration success, and the long-term stability of restored forests after large-scale wind disturbances.

7.2. Pilot area in Agordino, Italy

Background

The Vaia storm of 2018 caused unprecedented forest damage south of the Alps. In the northeastern Italian alps approximately 48,000 hectares of forest were affected, and around 80% of the estimated >16 million m^3 of damaged timber was salvage logged. The severely impacted Agordino valley in the Dolomites (Belluno Province) now serves as an open-air laboratory for investigating forest restoration in former protection forests and timber production forests.

Figure 32: Pilot Action area in Agordino, Italy. (© Tommaso Baggio, UNIPD)

Implementation

To investigate the role of biological legacies in forest restoration, two experimental trials were established.

The first trial focuses on the role of remaining seed trees after large-scale disturbances for natural regeneration. Transects extending from remaining forest edges into salvage-logged areas were established to investigate the influence of distance from seed sources, soil cover, site conditions and browsing pressure on tree regeneration patterns. Plots located 0, 20, 40, and 80 m from the forest edge were monitored to evaluate spatial regeneration dynamics.

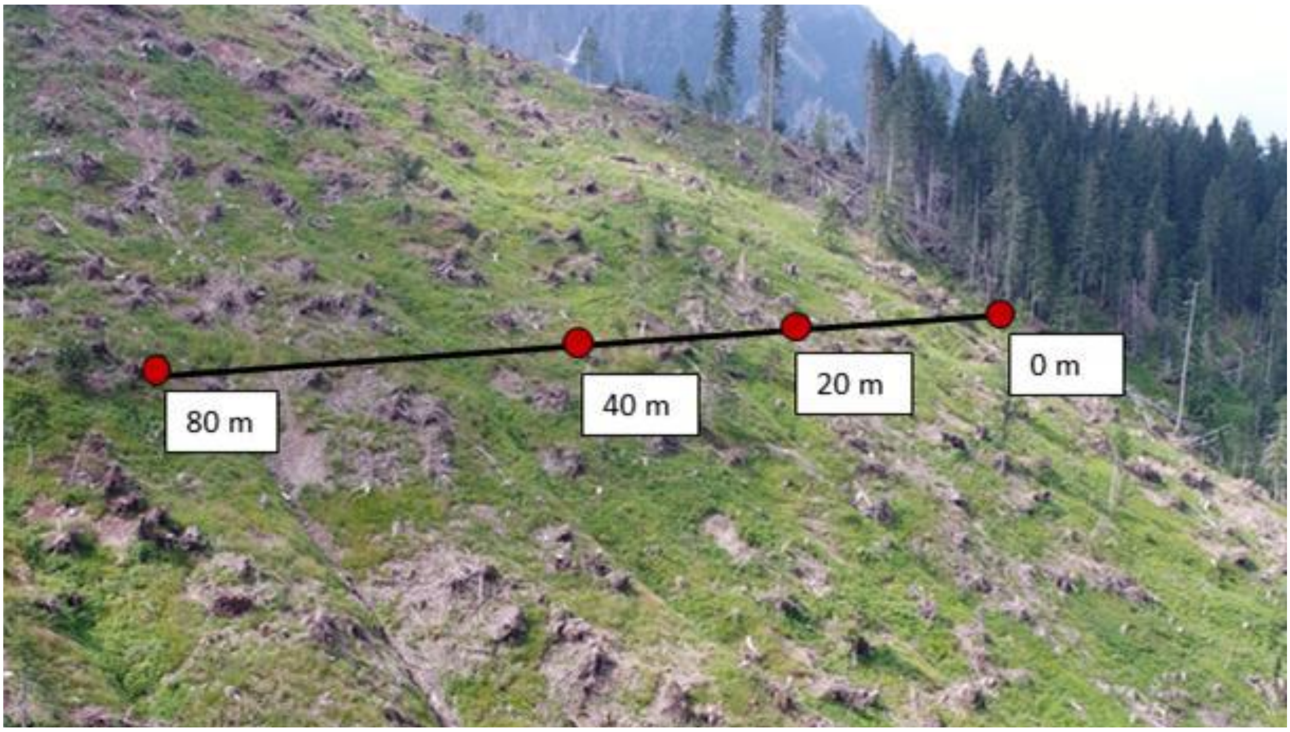

Figure 33: Illustration of transects extending from remaining forest edges into salvage-logged areas. (© Davide Marangon, UNIPD)

The second trial of Malgonera aims to quantify the role of deadwood in creating favorable microclimatic conditions for forest regeneration and browsing protection. In 2020, five tree species (*Picea abies* (L.) H. Karst, *Abies alba* Mill., *Larix decidua* Mill., *Fagus sylvatica* L., and *Sorbus aucuparia* L.) were planted in groups on different microsites near deadwood logs – one group on the north-facing side and one on the south-facing side of the log – as well as a control group planted approximately 2 m away on open ground. These experimental plots were placed on a steep south exposed slope, repeated randomly both on the forest edge and into the core wind-thrown area in order to assess how the presence of deadwood influences browsing pressure across the disturbed site. Soil temperature and moisture are monitored to evaluate the influence of deadwood on local microclimatic conditions.

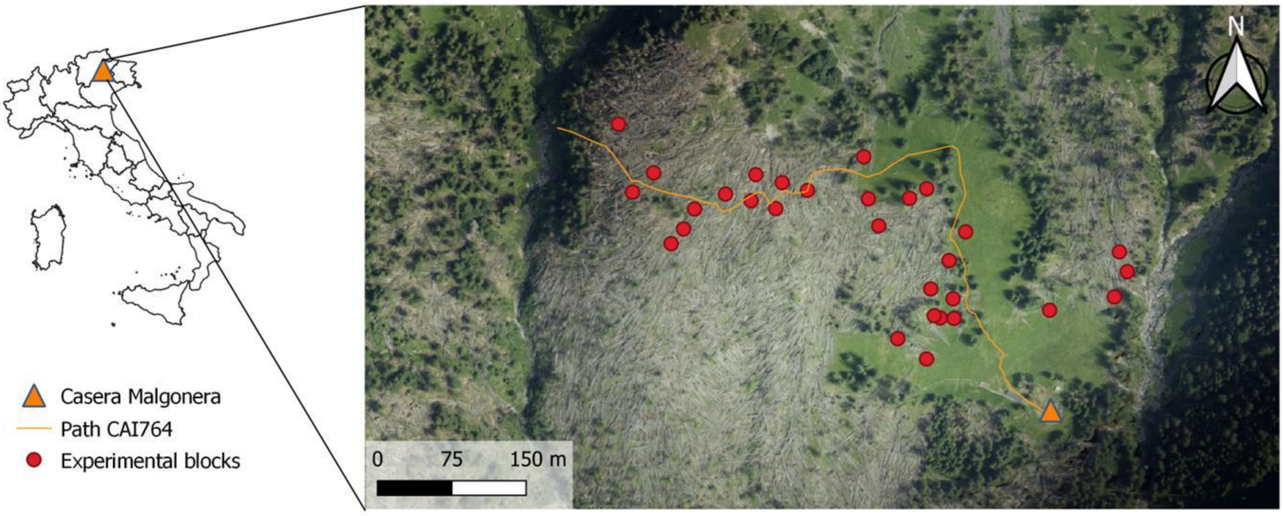

Figure 34: Map of the experimental transect for assessing the influence of deadwood on regeneration (Marangon et al., 2022).

Preliminary findings

Preliminary results highlight the strong influence of biological legacies on post-disturbance forest regeneration. Within 20 m of standing seed trees, natural regeneration density was highest. Regeneration was lower directly at the forest edge (0 m), likely due to unfavorable light conditions, and declined again beyond 20 m, demonstrating the strong influence of distance from seed sources. Natural regeneration of Norway spruce (*Picea abies* (L.) H. Karst), silver fir (*Abies alba* Mill.), and rowan (*Sorbus aucuparia* L.) showed the highest numbers of young individuals. However, browsing pressure did not reflect the occurrence of these species and instead showed a strong selective pattern. Less common species such as *Alnus alnobetula* (Ehrh.) K. Koch, *Salix caprea* L., and *Sorbus aria* (L.) Crantz experienced significantly higher browsing damage (up to 70–100%), while common species such as Norway spruce were only marginally affected, indicating food preference of the browsing animals.

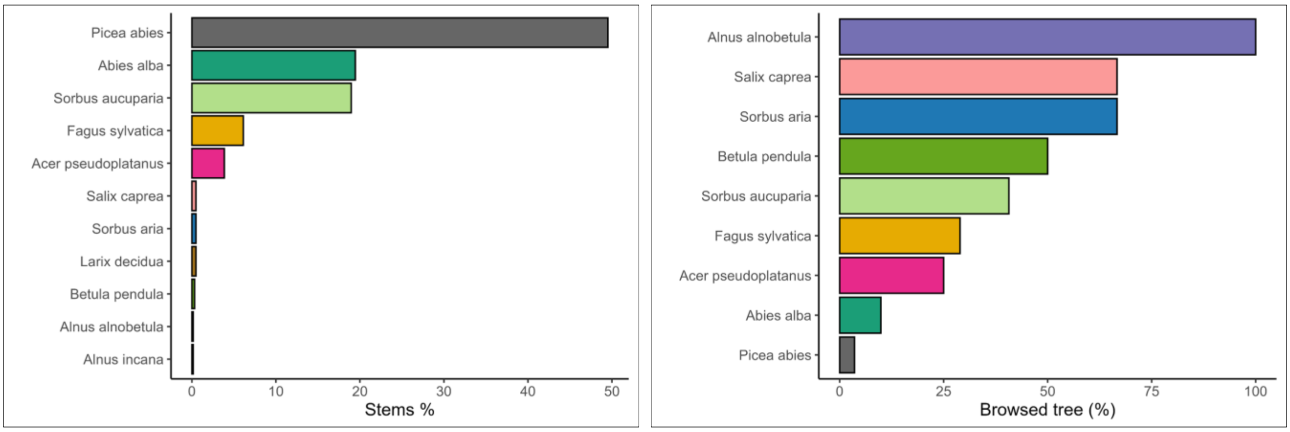

Figure 35: Share of tree species in natural regeneration (left) and share of individuals damaged by browsing per tree species (right) (Marangon et al., 2022).

In the planting experiment of Malgonera, deadwood also appears to represent an effective nature-based solution supporting seedling survival after large disturbances. The relative position of deadwood strongly influenced seedling mortality. Seedlings planted on the north-facing side of deadwood logs showed the lowest mortality rates, while seedlings planted on open ground experienced the highest mortality. Mean soil temperature was significantly lower on the north-facing side compared to the south-facing side and the control plots, highlighting the role of deadwood in creating favorable microsites for regeneration. Browsing damage showed a clear spatial pattern across the experimental area. The highest browsing intensity occurred along the forest edge, while almost no damage was observed within the core wind-thrown area containing scattered deadwood. This suggests that browsing animals tend to avoid areas that are difficult to access where the regeneration hides between woody debris, thereby concentrating browsing pressure along the edges of disturbed areas.

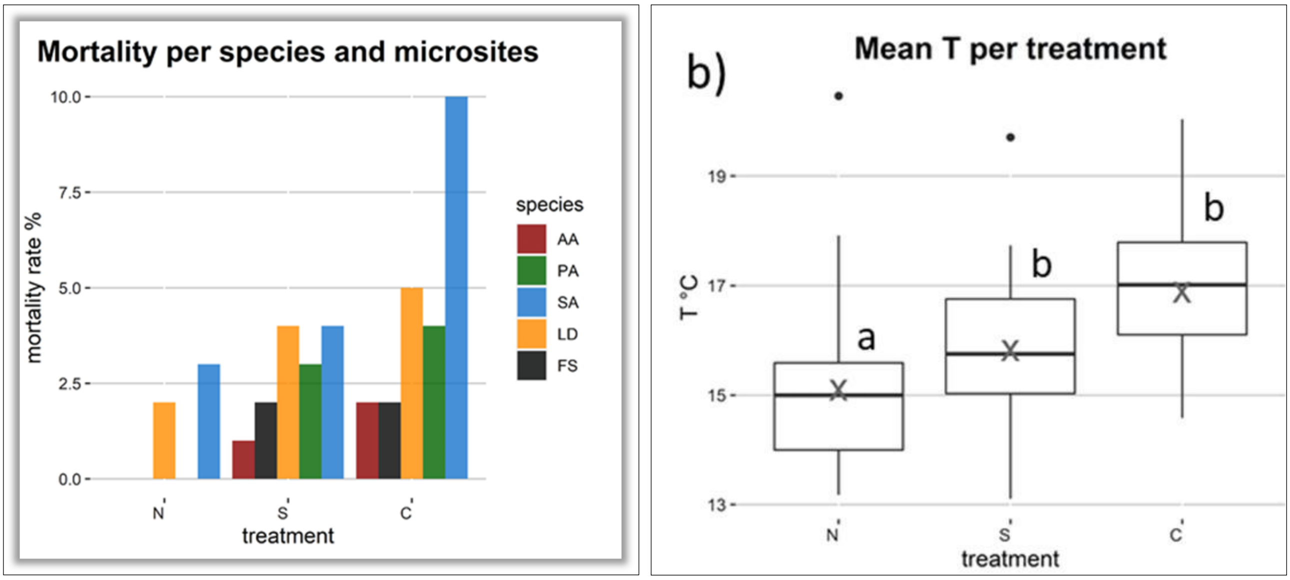

Figure 36: Preliminary results on the effect of the relative location of the sites in relation to deadwood logs (N = North, S = South, C = Control) on mortality (left) and temperature (right) (Marangon et al., 2022).

Overall, preliminary findings highlight the importance of biological legacies such as standing seed trees and deadwood as nature-based solutions for forest restoration after windthrow. Continued monitoring will provide valuable data on early regeneration trends and long-term forest development, enabling the formulation of practical recommendations for local and international stakeholders to support forest recovery processes.

In addition, expanding data collection to include nearby restoration areas where local forest managers have implemented different management interventions strengthens collaboration with regional stakeholders and supports the development of scientifically informed restoration strategies.

D. Synthesis of Lessons Learned

The Pilot Actions implemented within the RE-ENFORCE project address key drivers of forest degradation across Central Europe, including ash dieback, drought, bark beetle outbreaks, fire, storm disturbances, and improper management of riparian forests. Although ecological conditions, disturbance regimes, and restoration approaches differ across the pilot areas, several overarching insights have emerged from implementation and early monitoring. These lessons highlight key factors influencing restoration success and provide practical guidance for climate-adaptive forest management across the region.

Increasing forest diversity enhances forest resilience.

Several Pilot Actions confirm that structurally and compositionally diverse forests are more resilient to disturbances. In the ash dieback pilot areas in Hungary (PA1), homogeneous ash-dominated stands were severely affected by the host-specific fungal pathogen, often resulting in large-scale stand collapse, while mixed stands showed greater resistance and regeneration potential. Active diversification is therefore applied as a key restoration strategy across multiple Pilot Actions. In the storm-disturbed forests in Italy (PA6) and the riparian forests in Hungary (PA4), a mix of tree species is promoted to enhance structural and functional diversity. Similarly, in the bark beetle pilot area in Austria (PA5), restoration strategies aim to transform formerly pure conifer stands into mixed forests with deciduous species such as oak, hornbeam, and lime. These observations underline the importance of tree species diversity as a fundamental strategy for building more resilient forest ecosystems under changing environmental conditions.

Natural regeneration and biological legacies support forest recovery.

The Pilot Actions highlight the significant role of natural regeneration processes and biological legacies in post-disturbance forest recovery. In the storm-disturbed forests of the Agordino area in Italy (PA6), regeneration density was highest in proximity to remaining seed trees, demonstrating the importance of seed sources. Deadwood further contributed to favorable microclimatic conditions, improving seedling survival and influencing browsing patterns. Comparable dynamics were observed in the fire-affected forests in Poland (PA3), where passive restoration enabled the successful establishment of diverse tree species. In the post-fire pilot area in Agordino, Italy (PA3), ongoing trials investigate how biological legacies such as deadwood create suitable microsites for regeneration. These findings emphasize that retaining structural elements such as standing trees, seed sources, and deadwood represents an effective nature-based solution to support forest recovery after large disturbances.

Active restoration measures remain necessary in many situations.

While natural processes are essential for forest recovery, several Pilot Actions demonstrate that active restoration measures are often required to restore ecosystem functions or achieve specific management objectives. In the ash dieback pilot areas (PA1), artificial regeneration with multiple tree species was necessary where natural regeneration alone proved insufficient. Similarly, in the riparian forests of the Duna-Dráva National Park in Hungary (PA4), targeted interventions such as thinning, removal of invasive species, and enrichment planting were implemented to improve stand structure and species composition. This is particularly evident in large-scale windthrow areas, such as the pilot site in Toruń, Poland (PA6), where experimental plots investigate how seedling type, soil preparation, and tending intensity influence restoration success. These examples illustrate that combining natural regeneration with targeted interventions can provide effective restoration strategies under degraded conditions. Furthermore, legal frameworks often require active forest restoration within two to five years after a disturbance, so passive restoration is not usually the preferred approach.

Game browsing represents a major challenge for forest restoration.

High browsing pressure was identified as a critical limiting factor for forest regeneration in several pilot areas. In the ash dieback restoration sites (PA1), fencing or individual tree protection was required to safeguard planted seedlings. In the bark beetle pilot area in Austria (PA5), browsing pressure influenced planting density and required coordinated adjustments in regional hunting management. Similarly, observations from the storm-disturbed forests in Italy (PA6) showed selective browsing that disproportionately affected less common tree species. These findings highlight that successful forest restoration requires integrated wildlife and forest management strategies alongside silvicultural measures.

Restoration strategies must be adapted to site-specific conditions and future climatic conditions.

The Pilot Actions demonstrate that effective forest restoration depends strongly on local ecological conditions, disturbance history, legal frameworks, and management objectives. In the fire-affected forests in Poland (PA3), sandy soils and exposure to drought and wind erosion required careful consideration of site preparation techniques and planting material. In riparian forests (PA4), restoration measures needed to account for altered hydrological conditions and light availability. Similarly, the storm-disturbed sites in Italy (PA6) highlighted the importance of spatial factors such as seed source distance and microsite conditions created by deadwood.

In addition, several Pilot Actions underline the importance of anticipating future climatic conditions. In the post-fire pilot area in Agordino, Italy (PA3), experimental trials are testing assisted species migration by introducing downy oak (*Quercus pubescens* Willd.), a species expected to be better adapted to future climate conditions. In the bark beetle pilot area in Austria (PA5), restoration strategies focus on transforming vulnerable conifer-dominated stands into mixed forests with more drought-tolerant deciduous species. These examples demonstrate that restoration strategies must be tailored not only to current site conditions but also to expected future disturbance dynamics.

Long-term monitoring is essential to evaluate restoration success.

Forest restoration processes unfold over long time scales, often spanning decades. Several Pilot Actions therefore emphasize the importance of continued monitoring to evaluate the effectiveness of restoration measures. In the windthrow pilot area in Toruń, Poland (PA6), long-term monitoring of experimental plots will help assess how planting material, soil preparation, and tending regimes influence restoration outcomes. In the bark beetle pilot area (PA5), monitoring focuses on whether newly established mixed stands can combine climate resilience with economically viable timber production. Experimental trials in the drought-related pilot areas in Croatia and Czechia (PA2) investigate the long-term effects of drought stress on seedling performance. In the post-fire pilot area in Italy (PA3), recently established plots will provide future insights into assisted migration and nature-based restoration approaches. These monitoring activities are essential to better understand long-term ecosystem dynamics and to support adaptive forest management.

Pilot Actions function as demonstration sites and learning platforms.

Beyond their scientific value, the pilot areas of the RE-ENFORCE project play an important role as demonstration sites for forest practitioners and stakeholders. Many Pilot Actions were implemented in close cooperation with forest owners, protected area managers, and local authorities, allowing restoration approaches to be tested under real management conditions. By documenting interventions, monitoring results, and practical experiences, the pilot areas provide transferable knowledge that supports the wider application of nature-based solutions across Central Europe and beyond.

Overall, the Pilot Actions demonstrate that successful forest restoration requires a combination of ecological knowledge, adaptive management, and long-term monitoring. The experiences gained within the RE-ENFORCE project highlight the importance of integrating natural processes, targeted interventions, and stakeholder collaboration to restore degraded forests and strengthen their resilience to climate change. As experimental and demonstration sites, the pilot areas generate valuable knowledge that can support forest managers and policymakers in developing and implementing climate-adaptive restoration strategies across the Central European region.