Interreg Alpine Space

Co-funded by the European Union

MOSAIC

Protective Forest Management in the Alps, an illustrated guide

Catalogue of illustrated fact sheets for supporting integrated and adaptive forest management in climate action plans

MOSAIC – Managing protective forest facing climate change compound events

This deliverable will continue to be refined and integrated until the conclusion of the MOSAIC project. The final version will supersede the present version on the project website and web atlas and is expected to be made available in April 2026.

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MOSAIC, Interreg, Alpine Space

The main goal of the project MOSAIC is to support the Alpine Space program objective: Promoting climate change adaptation and disaster risk prevention, resilience, taking into account ecosystem-based approaches.

Therefore, MOSAIC focuses on hazard-resilient and sustainable protective forest management coping with climate changes' multiple dimensions, which is essential for managing climate-related risks. In order to support regional and alpine climate action plans, the project aims to collect, harmonize and share data, model alpine climate-related disasters trends, and protective forest effects. The project partners strive to raise awareness among foresters, risk managers, decision makers and the public through a network of forest living labs in the European Alps.

Activity 3.3 Catalogue of illustrated fact sheets for supporting integrated and adaptive forest management in climate action plans

Production of a catalogue of illustrated fact sheets for supporting integrated and adaptive forest management of protective forests in climate action plans. Based on results from WP1, WP2 and forest living labs, a collection of best practice examples and silvicultural measures for forest resilience and climate change adaptation is presented in a catalogue with an innovative approach with illustrations and infographics.

1. Introduction

Mountain forests play a vital role in protecting people, infrastructure, and livelihoods from natural hazards. These protective forests are defined as forests whose primary function is to protect society and assets from hazards such as snow avalanches, rockfall, landslides, debris flows, floods, and the growing impacts of adverse climatic conditions (Brang et al. 2001).

Understanding what a forest protects and where (its protective function) and how well it fulfills this role (its protective effect) is at the core of sustainable protective forest management (Teich et al. 2022). Protective forests are not static: their effectiveness depends on forest structure, species composition, regeneration, disturbance regimes, and long-term ecological stability. At the same time, they must meet social, economic, and ecological sustainability criteria, often under competing land-use pressures and changing environmental conditions.

Climate change is altering the environmental conditions that influence protective forests and the provision of their protective functions. Rising temperatures, shifting precipitation regimes, more frequent extreme weather events, drought stress, and large-scale disturbances such as windthrow or bark beetle infestations all influence forest stability and regeneration. At the same time, hazard processes themselves are changing. Protective forests are increasingly facing compound events, where multiple hazards or stressors interact, for example, heavy rainfall following drought and wildfire, or storms combined with saturated soils. These cascading processes can severely affect forests that lack resilience, reducing their protective effect when it is needed most.

For these reasons, protective forests are a key example of a forest-based solution (FbS), a specific type of nature-based solution (NbS), for disaster risk reduction (DRR) and climate change adaptation (CCA). When sustainably managed, they provide a no-regret strategy: even under uncertain future climate conditions, strengthening forest resilience delivers multiple co-benefits such as carbon sequestration, biodiversity conservation, water regulation, recreation, and support for local economies.

This catalogue of illustrated fact sheets was developed to support that need. It provides a structured collection of infographics and fact sheets presenting best practices, silvicultural and biotechnical measures for strengthening the resilience and protective effect of forests in the context of climate change and compound events. It is designed to support integrated risk management (IRM) and adaptive forest management within climate action planning, linking Eco-DRR measures, NbS, and sustainable forestry.

The work builds on results from WP1 and WP2, as well as knowledge generated in Forest Living Labs (FLLs), where scientists, practitioners, and stakeholders jointly tested and discussed management approaches. These FLLs ensured that the measures presented are not only scientifically sound but also operationally feasible and socially relevant.

A key tool for knowledge transfer in this process has been the Marteloscope approach. These training plots allow forest practitioners and decision-makers to simulate silvicultural interventions in a realistic stand, assess their effects on structure, stability, habitat value, and protective effects, and discuss trade-offs. Combined with the FLL approach, Marteloscopes bridge the gap between research and practice and foster a shared understanding of adaptive management under uncertainty.

The overall goal of this catalogue is to make complex knowledge on protective forests accessible, visual, and actionable. By combining science, practice-based experience, and innovative visual communication, it supports forest managers, planners, and policymakers in managing forests that continue to protect society — not only today, but under the uncertain and changing conditions of tomorrow.

2. Silvicultural measures in protective forests

The forest ecosystem can effectively mitigate natural hazards such as avalanches, rockfall, landslides, debris flows, and soil erosion. In mountainous and hazard-prone regions, protective forests constitute a nature-based solution that complements technical protective measures and often represents the most sustainable and cost-effective form of long-term risk reduction. The effectiveness of protective forests, however, is not static. Their protective functions depend on forest structure, species composition, vitality, and stability, all of which are shaped by both natural dynamics and forest management measures, carried out in the certain forest area. Both living and dead trees present obstacles that stop or slow down falling rocks and can prevent or reduce slope movements, such as landslides and rock slides or mass (debris and mud) flow.

Silvicultural measures are a key instrument for ensuring that protective forests maintain and enhance their functionality over time. While protective forests have traditionally been perceived as areas where intervention should be minimized, growing evidence shows that passive management alone is often insufficient to guarantee their long-term protective effect. The ability of a forest to effectively protect against natural hazards depends to a large extent on the structure and long-term stability of the forest, which we can influence through our management. Climate change, increasing disturbance regimes (such as storms, droughts, insect outbreaks, and wildfires), altered regeneration patterns, and legacy effects of past management have increased the vulnerability of many protective forests. Without targeted silvicultural interventions, these forests may lose their structural integrity, resilience, and capacity to effectively mitigate natural hazard, which is often represented by compound events - a combination of multiple climate-related hazards that contribute to socio-ecological risks.

Active forest management in protective forests aims to steer forest development in a way that sustains or improves protective functions while respecting ecological processes. Silvicultural measures such as selective thinning, regeneration management, species diversification, shaping of stability-oriented stand structures, and the promotion of uneven-aged, multilayered canopies structures contribute to enhanced resistance and resilience against disturbances. By actively managing stand density, tree size distribution, rooting stability, and regeneration continuity, forest managers can reduce the risk of large-scale stand failure and ensure continuous protective coverage.

Furthermore, active management enables adaptive responses to changing environmental conditions. Anticipatory silviculture that considers future climate scenarios, site conditions, and hazard dynamics is increasingly important to maintain protective functions in the long term. Well-designed silvicultural measures can strengthen the multifunctionality of protective forests, balancing hazard mitigation with biodiversity conservation, carbon storage, and socio-economic objectives.

The infographics presented in this catalogue, focus on condensed presentation of main silvicultural measures in protective forests, highlighting their characteristics, assessment and their role in maintaining and enhancing protective functions. Special emphasis is placed on its role in active forest management to ensure that protective forests remain effective, resilient, and capable of fulfilling their critical role in a changing environment.

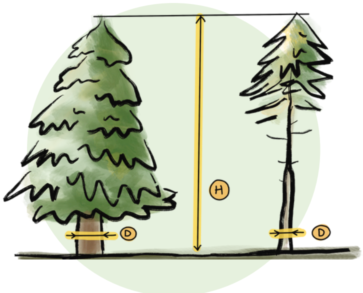
IMPROVING FOREST STAND STABILITY

Forest stand stability refers to the ability of a forest to **withstand natural disturbances** such as wind, snow, pests, rockfall etc. It depends on the mechanical and ecological stability of **individual trees**, as well as the s**tructural resilience of the stand** as a whole.

Assessment

Mechanical stability of individual trees can be assessed using indicators, such as:

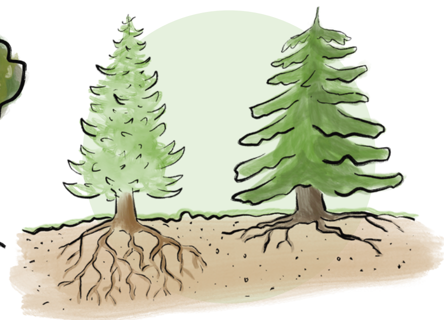
height-to-diameter ratio HDR



stem inclination

crown asymmetry

root system development



Importance for protective forests

Forest stand stability is essential in protective forests, which must maintain their protective functions under unpredictable natural events.

Immplementation requirements

Optimal stability requires targeted silvicultural measures at all development stages, including thinning to improve structure and diversity, removing old or heavy trees, ensuring timely natural regeneration and avoiding overly large gaps. Openings should be oriented horizontally along the slopes to reduce erosion and rockfall risk.

Threshold values

Optimal stability can be reached with high proportion of trees with:

- HDR below 80 : 1
- No or low stem inclination
- Symmetrical crowns
- Deep root system (e.g., larch)

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IMPROVING TREE SPECIES COMPOSITION UNDER CLIMATE CHANGE

Tree species composition refers to the **proportion and arrangement** of different **tree species within a forest stand**, such as broadleaves and conifers, indicating how mixed or uniform the forest is in terms of species diversity.

Assessment

Tree composition can be assessed, using the following indicators:

- **Tree species mixture**
- **Naturalness of tree composition**
- **Root system** (% of trees with deep root system e.g. larch)
- **Crown cover** (for avalanches)
- **Share of evergreen conifers** (for avalanches)

Importance for protective forests

Deep-rooted species stabilize slopes and reduce landslide risk, while structural diversity improves the forest's capacity to intercept and slow rockfall. Canopy cover moderates snow accumulation, decreasing the potential for avalanche release. Site appropriate species composition enhances long-term forest stability and ensures continued mitigation of natural hazards in a changing environment.

Immplementation requirements

Selection of resilient tree species through single-tree harvesting and controlled mixed-growth management are essential. Desired species should be retained to guide stand development, while valuable mixed species are preserved to support long-term natural regeneration. Enrichment planting may be applied where necessary to strengthen species diversity. All interventions should be conducted with minimal disturbance to maintain continuous forest cover, and management should aim to create uneven-aged forest structures.

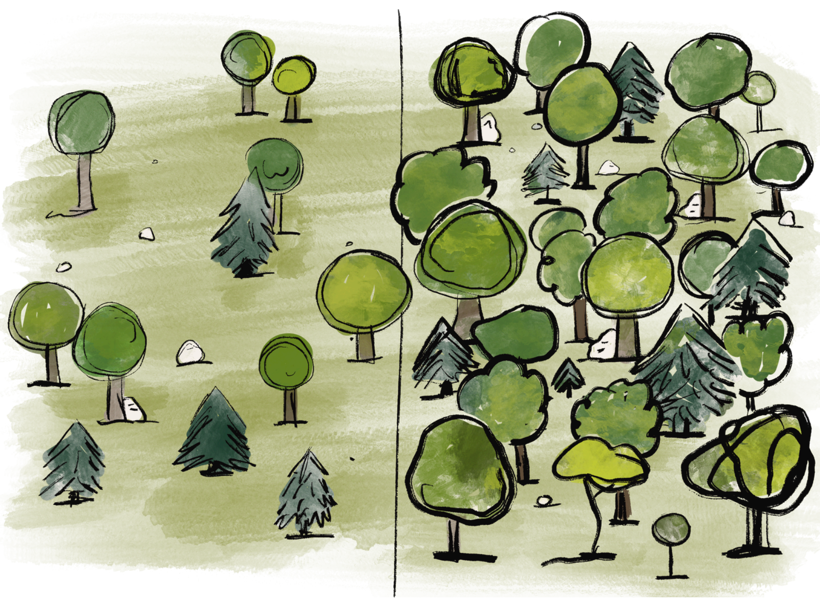
OPTIMAL SPATIAL DISTRIBUTION OF TREES

The spatial distribution of trees in protective forests refers to their **position, arrangement** and **density** along the slope. These factors collectively influence the forest's effectiveness in stabilizing the terrain and mitigating slope-related processes such as landslides, rockfalls and erosion.

Assessment

Spatial distribution is assessed based on the location of individual trees and can be described using the following indicators:

- **Basal area** (m^2/ha)
- **Stem density** (number of trees/ha)
- **Average distance between trees**
- **Spatial location** of trees on a map
- **Distribution** of trees across **diameter classes**



Importance for protective forests

Optimal spatial distribution is a key parameter in establishing a forest's protective function for mitigating snow avalanche release, rockfall and shallow landslides, as it reduces hazard intensity by decreasing kinetic energy.

Immplementation requirements

Optimal spatial distribution in forest stands requires adequate and targeted management across different developmental stages.
The selective removal of large trees is crucial for initiating natural regeneration and/or promoting the growth of established regeneration. Early wide spacing and thinning further enhance stand structure, leading to a spatial distribution, that supports protective and management objectives.

GAPS MANAGEMENT

Gaps are **locations** where the **tree cover** in a forest stand is **interrupted** for certain reasons (logging, dying trees, natural disturbances). **Regeneration** in these areas **can benefit** from increased light availability at ground level and greater growing space, but it may be limited by competition from shrubs and herbaceous plants.

Assessment

Analyzing the **spatial distri-bution of trees** together with variations in **relative crown area** enables the **identifica-tion of areas without forest cover**, as well as a precise assessment of the **size and orientation of forest gaps.**

Importance for protective forests

Gap characteristics help identify the spatial distribution of potential release areas for snow avalanches. In the case of rockfalls, forest gaps can increase the velocity and kinetic energy of falling rocks due to the absence of obstacles. Similarly, for shallow landslides, the lack of tree root systems within gaps reduces soil reinforcement, thereby increasing the susceptibility to slope instability and mass movements. Therefore, gap size and orientation are key parameters in ensuring protective function in forests exposed to gravitational hazards.

Immplementation requirements

Gaps are essential structures for stand regeneration, but if they are too big, the risk of natural hazards can dramatically increase. The management should avoid the creation of large gaps, especially in the direction of the slope at all developmental stages of the stand.

Threshold values

Gaps **larger than 1-2 times the height** of the surrounding trees should be avoided.

NATURAL REGENERATION MANAGEMENT

Natural regeneration is the process by which new trees grow from seeds, sprouts or seedlings present in the forest without artificial planting. It maintains the forest's **natural structure, species composition** and **genetic diversity.**

Assessment

Key inidicators include:

- **Presence of natural regenration** on an area
- **Species, quantity and vitality** of seedlings
- **Naturalness of tree composition**
- **Constant forest cover**
- **Impact of ungulates and herbivores**

Immplementation requirements

To achieve optimal natural regeneration, management must gradually introduce light into the stand by selectively removing mature trees, creating small gaps that stimulate seed germination while avoiding excessive soil disturbance. Mixed species should be retained during harvesting to secure future regeneration potential, and young seedlings must be protected throughout felling and extraction operations. In areas lacking regeneration, small-group selection may be required to encourage establishment, with enrichment planting applied only where natural processes are insufficient.

Importance for protective forests

Natural regeneration ensures continuous replacement of aging trees with individuals adapted to local site conditions. Regeneration originating from the existing stand maintains appropriate species composition, structural diversity and stand stability with root systems suited to microsite conditions, enhancing slope reinforcement and long-term stand resilience. Genetic diversity inherent in natural regeneration strengthens adaptive capacity under increasing climatic pressures, while preserving permanent forest cover essential for hazard mitigation.

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ACTIVE RESTORATION THROUGH PLANTING AND SEEDING

Active restoration is essential when **natural regeneration is scarce, delayed or insufficient**, or when ecosystem resilience needs **improving due to climate change**.

It involves **planting or seeding** to accelerate forest recovery, target desired species, select suitable sites and maintain genetic diversity, supporting both ecosystem dynamics and protective forest functions.

Assessment

Effectiveness can be evaluated through recruitment rates:

- **Seedling emergence**
- **Seedling growth and conditions**

Continuous monitoring identifies issues and guides additional interventions. Indicators include:

- **Seedling density**
- **Species composition**
- **Spacing schemes.**

Importance for protective forests

Regeneration ensures continuity of protective functions. Rapid establishment stabilizes stands and slopes. Seeding improves root development, while young trees supported by deadwood increase surface roughness, reducing rockfall and avalanche intensity. Active restoration also enhances species diversity and climate resilience.

Immplementation requirements

Successful outcomes require careful timing, site, species and provenance selection. Seedlings should have well-developed roots and proper root/shoot ratios. Browsing must be managed. If able, microsites near deadwood or sheltered areas should be favored. Retaining deadwood helps protect seedlings and reduce hazards. Hydrogels can aid survival on steep or dry slopes. Monitoring seedlings to guide adaptive management and maintain protective function is essential.

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INTEGRATED DEADWOOD MANAGEMENT

Lying deadwood increases **surface roughness**, enhances **protection against hazards**, and creates **favorable microsites** for seedling establishment by moderating temperature, moisture and browsing pressure. It also supports biodiversity by providing habitat and resources for forest organisms. Retaining deadwood after severe disturbances helps maintain protective functions, supports regeneration and sustains ecosystem diversity.

Assessment

The indicators, that can be used are:

- **Type of deadwood elements** (snags, logs, stumps),
- **Decomposition level** (to assess protective effects and nutrient release),
- **Mass and volume of deadwood** elements
- **Spatial distribution** of deadwood elements (piles, randomly distributed etc.)

Importance for protective forests

Lying deadwood mitigates rockfall by slowing or deflecting rocks and in avalanche zones, increases structural roughness, preventing glide-snow avalanches, stabilizing snowpacks and reducing slab and loose-snow avalanche risks.

Immplementation requirements

Management must carefully balance the undeniable ecological benefits with safety needs. Deadwood retention should be planned by considering proximity to roads, trails, infrastructures or settlements, where risks to people may require selective removal or stabilization. In these areas, cutting damaged or dead trees may result in logs, that can be moved somewhere else (i.e., **deadwood manipulation**).

Threshold values

Recommended thresholds include:

- ⩾2 logs every 10 m (diameter ⩾ rock size in gaps >20 m)
- Minimum stump height 1.3 m
- Sufficient volume per hectare.

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3. Biotechnical measures in protective forests

In situations where silvicultural measures alone cannot sufficiently improve or restore the protective function of forests, biotechnical measures offer an effective complementary approach. These measures combine biological material with simple technical elements to stabilize slopes, reduce surface processes, and support forest regeneration. Compared to purely technical solutions, biotechnical measures are generally less invasive, more cost-effective, and better integrated into natural forest dynamics.

Biotechnical interventions are particularly relevant in degraded protective forests, on steep slopes, or in areas affected by disturbances where forest cover is temporarily insufficient to mitigate hazards such as shallow landslides, rockfall, and snow movements. Measures such as slope stabilization using cuttings and seedlings, fascines and willow wattling, high stumps, targeted cutting of damaged trees, ground-level cut stumps, horizontally placed logs, anchored logs, alpine cutting techniques, and piles of branches or logging residues can significantly enhance slope stability and create favorable conditions for natural regeneration.

The infographics presented in this catalogue focus on a condensed and practical overview of key biotechnical measures in protective forests, highlighting their main characteristics, application conditions, and contribution to slope stabilization and hazard mitigation. Special emphasis is placed on their role in active forest management, ensuring that protective forests remain effective, resilient, and capable of fulfilling their critical protective function under changing environmental conditions.

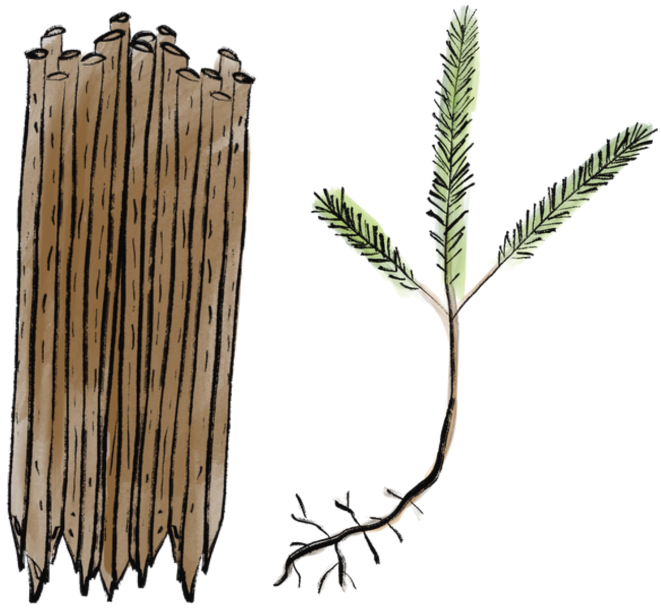
However, in cases where the protective function of the forest is severely impaired or cannot be ensured in the short term, technical measures, such as catch fences, deflection structures, and other engineered solutions, remain necessary to protect assets at risk. Biotechnical measures should therefore be understood as a bridge between forest management and technical hazard mitigation, supporting long-term, ecosystem-based protection strategies in protective forests.

SLOPE STABILIZATION WITH CUTTINGS AND SEEDLINGS

Definition

Cuttings are living sections of branches up to 2 cm in diameter and 30 cm long.

Seedlings are young plants, that originate from seeds and may be produced either in nurseries or in forest stands, through natural regeneration (wildings)



Importance for protective forests

- Due to their strong vegetative capacity, cuttings, especially willow, notably **narrow-leaved willow (*Salix exigua*)**, develop roots and shoots from dormant buds, binding soil particles and preventing surface erosion.
- Natural plant species adapted to the site should be chosen for wildings, e.g. **black alder (*Alnus glutinosa*)** for its deep root system.

Immplementation requirements

Cuttings—thumb-thick branches cut to length and bundled—are planted at an angle with buds upward, about 1 per m^2, in early spring to promote strong root development.

Wildings should be collected near erosion hotspots, kept out of direct sunlight, and planted in autumn under wet conditions to minimize root damage and ensure establishment.

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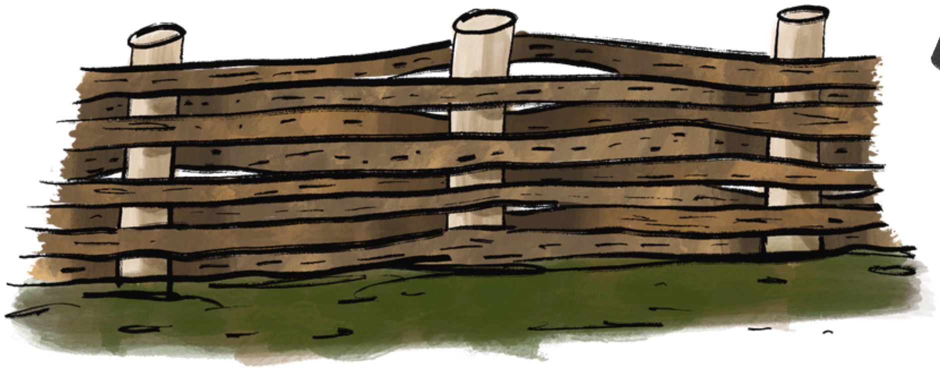
FASCINES AND WATTLE FENCES

Definition

Fascines are bundles of willow branches tied together and secured with wooden (willow) stakes.

Wattle fences consist of intertwined willow branches anchored into the bank with wooden stakes.



Importance for protective forests

Since **the branches are still alive**, they are capable of developing roots from the shoots. This structure **provides immediate protection** to the entire slope. Eroded material accumulates behind them and deposits forest debris, which creates new soil layer while preventing particle movement and erosion along the bank by acting as a physical barrier.

Immplementation requirements

Fascines are bundled willow branches (30–40 cm × 4 m) with buds facing the sun. They are laid across slopes at a slight angle, fixed with stakes, embedded in soil, spaced 2–3 m apart, and installed in early spring.

Wattle fences use stakes ⩾10 cm thick at 1 m intervals, with thin branches woven to 50 cm height, using basket-weaving technique. Branches can be soaked for flexibility and mulch (hay, grass, leaves, branches, soil) can be applied on top.

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HIGH AND LOW STUMPS FOR FOREST PROTECTIVE FUNCTION

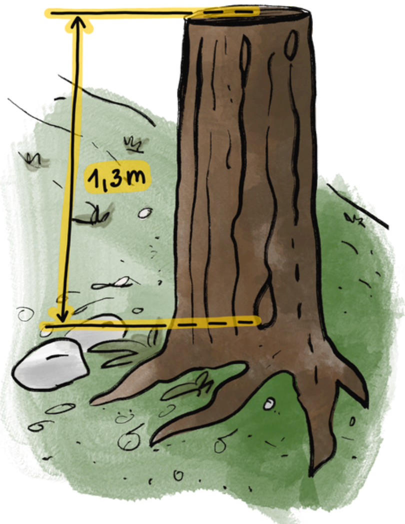
Definition

In order to improve the protective function of the forests on steep slopes after post-disturbance harvesting, there are several **stump manipulation techniques** that can be used, such as leaving out:

- high stumps at 1,3m
- stumps cut above the injurie
- low stumps

Importance for protective forests

High stumps (1.3 m) maintain protective function after harvesting by acting as surface roughness and physical barriers, preventing rockfall from reaching the road.



Cutting stumps above injuries helps retain rocks caught in the stem, maintaining protective function and preserving information on rockfall paths for future risk assessment.

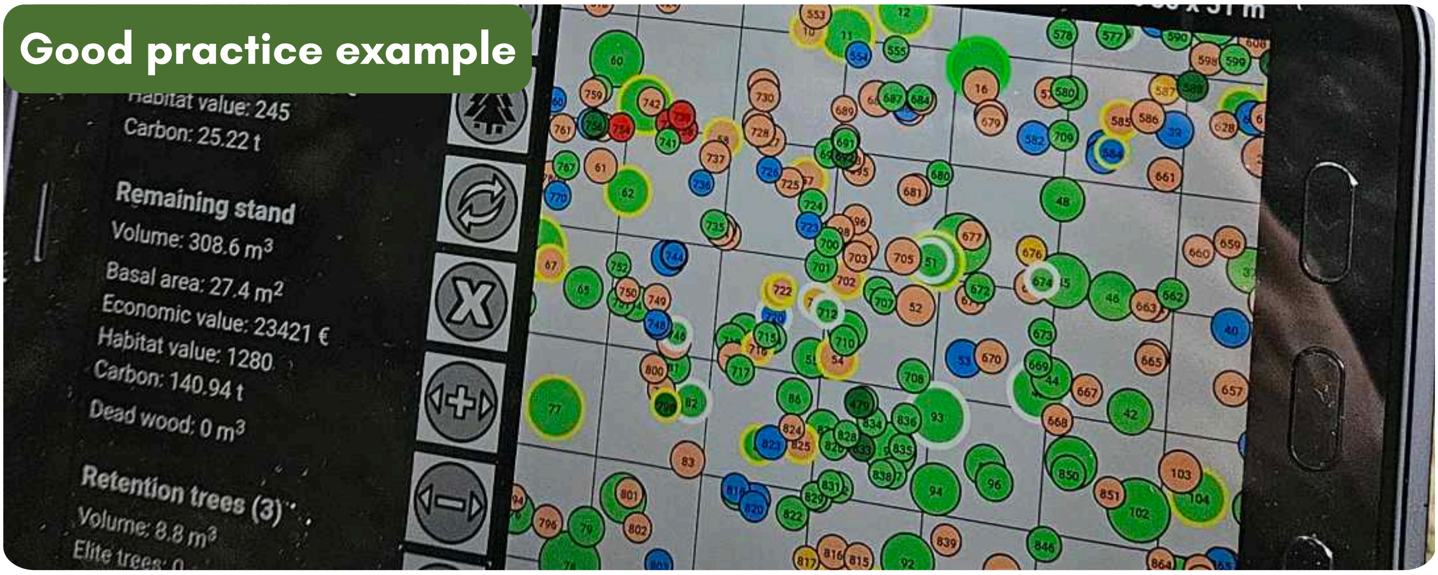
Very low stumps, cut just above the ground, reduce rock bounce, preventing a 'trampoline effect'.

4. Best practice examples, researches and case studies from alpine space countries

This chapter presents selected best practice examples, research outcomes, and case studies from Alpine Space countries, including Slovenia, Austria, France, Italy, and Switzerland. The contributions illustrate diverse approaches to managing protective forests and mitigating natural hazards under varying environmental, socio-economic, and institutional conditions across the Alpine region.

The examples are presented in the form of concise fact sheets, providing structured and comparable information on objectives, applied measures, methodologies, and key results. Together, they highlight transferable solutions, innovative practices, and lessons learned that support evidence-based decision-making and the effective implementation of protective forest management in mountainous areas.

Good practice example



MARTELOSCOPE AS AN EDUCATIONAL TOOL FOR PROTECTIVE FOREST MANAGEMENT

What are Marteloscopes?

Marteloscopes are 1-hectare big forest plots where all trees are numbered, mapped and recorded. Combined with the I+ Trainer app, they serve as an effective tool for virtual silvicultural training, supporting education and knowledge transfer.

Protective module upgrade

The MOSAIC project, in collaboration with EFI, upgraded the I+Trainer app for virtual tree selection by adding a protective forest module, with protective forest indicators.

Importance for protective forest management

Protective forest management focuses on maintaining stand stability and preventing slope related processes. Marteloscopes help train forestry professionals in applying appropriate silvicultural measures in these sensitive areas.

Protective forest indicators

- Height/diameter ratio
- Root system
- Crown symetry
- Tree species composition
- Stand structure
- Regeneration
- Gaps
- Tree distribution
- Stand density
- Stand basal area
- Distance between trees
- Crown closure

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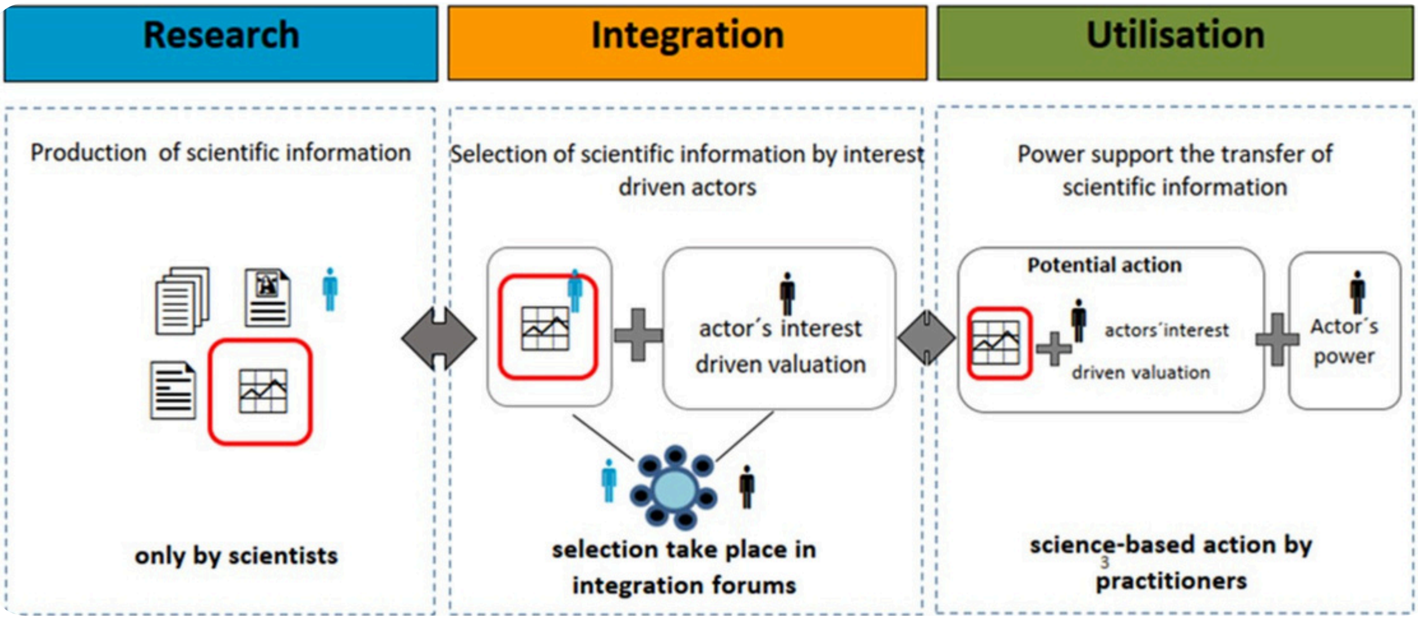
EFI

For more information visit: http://iplus.efi.int/



MAKING RESEARCH WORK: INTEGRATION FORUMS FOR EFFECTIVE NATURAL HAZARD MANAGEMENT

Tabea Schaefers
University of Göttingen (UNIGOE)

What are integration forums?

Integration forums are targeted formal or informal formats for sharing scientific knowledge with selected practitioners. Examples include workshops, expert panels, or short practice-oriented publications. They help reach actors who are both interested in the topic and able to implement concrete measures or processes, ensuring research is relevant and actionable.

Connecting research and practice

The RIU model frames integration forums within the knowledge transfer process, from Research through Integration to Utilization. In the integration phase, scientific findings are aligned with practical needs. Within that phase, integration forums provide structured opportunities to communicate results directly, allowing practitioners to apply insights more efficiently.

Putting knowledge into practice

Integration forums support precise and effective knowledge transfer. They help practitioners access relevant research early and share their own priorities. By using suitable forums, knowledge reaches actors who can implement it in practice, enabling well-informed decisions and actions in natural hazard management.

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For more information visit: https://link.springer.com/book/10.1007/978-3-319-34079-1

Good practice example

Slovenia

POST WINDTHROW NATURAL REGENERATION CAN PROVIDE MORE RESILIENT FORESTS

Research in Jelovica plateau, Slovenia

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1 Slovenia Forest Service, 2 University of Ljubljana

After the storm

Natural disturbances shape forest dynamics. After the 2006 windstorm in the Slovenian Alps, 160 ha of mature Norway spruce were damaged. Understanding natural succession is key for resilient, close-to-nature forest management.

Tracking nature's response

Regeneration on 125 ha was monitored using 81 permanent plots. Surveys in 2008, 2011, 2017 and 2025 recorded species composition, height classes, browsing, stand and site characteristics, as well as forest edge distance.

Supporting forest recovery

Within two decades, natural regeneration restored species and structural diversity, supporting long-term protective functions like soil stabilization, biodiversity and ecosystem recovery. Early tending and thinning can further improve forest structure.

Growth and diversity trends

Seedling density increased **from 8,380/ha (2008) to 12,400/ha (2025).**

Spruce dominated early, but **European beech and silver fir increased steadily.**

Seedlings shifted to taller height classes over time, showing **successful recruitment.**

Browsing affected smaller seedlings (<130 cm), mainly sycamore maple and European rowan.

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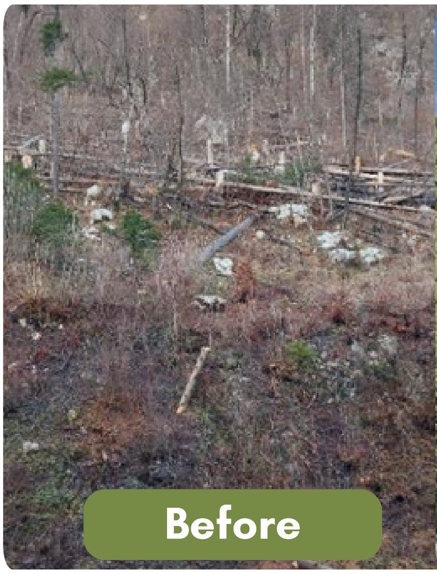
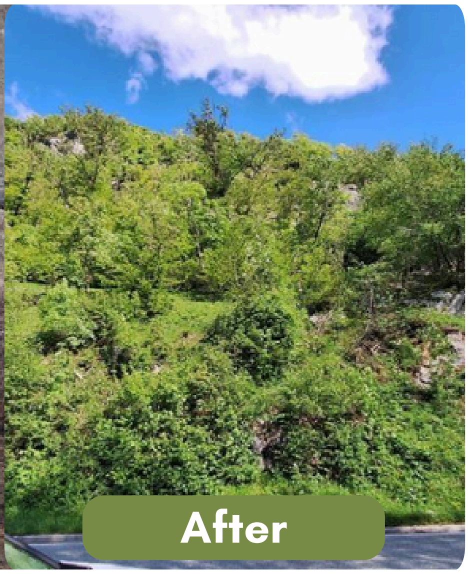
Good practice example

Slovenia





ENSURING PROTECTIVE FOREST FUNCTION USING NATURE-BASED SOLUTIONS IN SOTESKA, SLOVENIA

Magdalena Cholkova, Stane Kunej, Kristina Sever, Andrej Breznikar
Slovenia Forest Service (SFS)

Hazard risks

In the protective spruce forest above the main road in Soteska Valley, a bark beetle outbreak in areas lacking forest management, has caused frequent tree and rock falls.

Slope stabilization

A sanitary cut with additional biotechnical measures was carried out to stabilize the area and protect it from rockfall. Following the intervention, natural regeneration progressed successfully and additionally contributed to the successful protection of the road and the stand.
Biotechnical measures used:

- **High stumps** (1.3 m)
- **Logs anchored horizontally** on the slope (70° angle on the fall line)

Directional felling

In directional felling, it is crucial, that trees are healthy at the time of cutting. If they are already decayed, directional felling becomes hindered, as they may fall unpredictably and potentially collapse onto the infrastructure bellow.

Nature-based protection

Biotechnical measures implemented in the Soteska protective forest proved **highly effective.**

Following the sanitary felling with high stumps and anchored logs, rockfall onto the road stopped completely, and the stand began to regenerate naturally and successfully demonstrating, that **nature-based solutions can efficiently restore** both stability and protective function.

Furthermore, nature-based approach also turned out to be significantly **more cost-efficient than technical protective measures.**

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Good practice example

Slovenia

INNOVATIVE FOREST REGENERATION IN FIRE-AFFECTED AREAS

Magdalena Cholkova[1], Boris Rantaša[2], Kristina Sever[1]
1 Slovenia Forest Service (SFS), 2 Slovenian Forestry Institute (SFI)

Why are new approaches needed?

Frequent natural disturbances and accelerating climate change increasingly challenge natural regeneration, particularly on sites exposed to extreme conditions such as drought, shallow soils and steep terrain. These pressures necessitate targeted restoration techniques that enhance seedling survival and promote long-term forest resilience.

Restoration methods	Key results	Protective forest benefits
Planting seedlings with hydrogels and mycorrhiza.	Improved **moisture** retention, higher **seedling survival** and nutrient uptake.	Enhanced **erosion resistance** and **long-term protective functions.**
Drone seeding with seed bombs.	Rapid area coverage and **60–90% germination.**	Reforestation of **inaccessible terrain.**
Enrichment planting using site specific species.	Increased species **diversity**.	Ecosystem **resilience and adaptability.**

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For more information visit: https://alpineresilience.org/stories/slovenia-planting-seedings-using-hydrogel

Good practice example

Italy

EXPLOITING FACILITATION MECHANISMS BY DEADWOOD IN ACTIVE RESTORATION

Nicolò Anselmetto, Matteo Garbarino, Raffaella Marzano
Università di Torino (UNITO)

Deadwood as a recovery asset

Deadwood provides essential microsites that support post-fire recovery and should be valued as a restoration asset.

Incorporating microsite facilitation into restoration protocols (e.g., seeding near logs, shaded sides, shrub cover) significantly **improves establishment success.**

Combining landscape-scale priority modelling with microsite selection offers a cost-effective restoration framework.

Aligning restoration with ecological processes enhances resilience and long-term protective forest functions.

Post-fire regeneration

Deadwood facilitates post-fire forest regeneration by:

- **Protecting against grazing**
- **Shielding from solar radiation and buffering microclimate**
- **Reducing soil moisture loss**
- **Releasing nutrients during decay**

On south-facing slopes with Scots pine (*Pinus sylvestris*) and European larch (*Larix decidua*) affected by high-severity wildfires, harsh conditions limit natural regeneration. Active restoration can exploit deadwood facilitation by placing seeding or planting near logs, stumps or woody debris to enhance regeneration establishment. This case study integrates field protocols and scientific evidence to guide restoration where natural regeneration is insufficient.

Methods

- Identification of deadwood facilitation effect
- Determining seeding microsites and targeted interventions in priority areas
- Development of integrated seeding protocols
- Monitoring establishment and growth continuously

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For more information visit:
https://alpineresilience.org/stories/surprising-role-of-deadwood

Good practice example

Italy

PARTIAL SALVAGE LOGGING AND DEADWOOD MANIPULATION

Nicolò Anselmetto, Matteo Garbarino, Raffaella Marzano
Università di Torino (UNITO)

Hazard reduction

Deadwood plays an important role in mitigating the risk of natural hazards especially immediately after the occurrence of a natural disturbance.

Partial salvage logging is a post disturbance technique consisting of partially harvesting deadwood. In this way, forest owners can partially mitigate the economic loss due to forest natural disturbances, but at the same time retain some deadwood on the ground to reduce the risk of natural disturbances.

On the other side, deadwood manipulation is a technique oriented to build up mainly horizontal/diagonal structures along the slope made by stems to further increase the protection effect of the damaged area.

Planning deadwood-based protection

- **Identification** of the type of natural hazard to mitigate
- **Analysis** of the amount of deadwood to retain on site and/or type of deadwood manipulation structure to implement
- **Evaluation** of the duration of the mitigation effect of the deadwood and/or of the deadwood manipulation structures.

Salvage logging can create harsher microclimates and reduce regeneration potential. Its use should be limited to safety-critical zones (roads, infrastructures).

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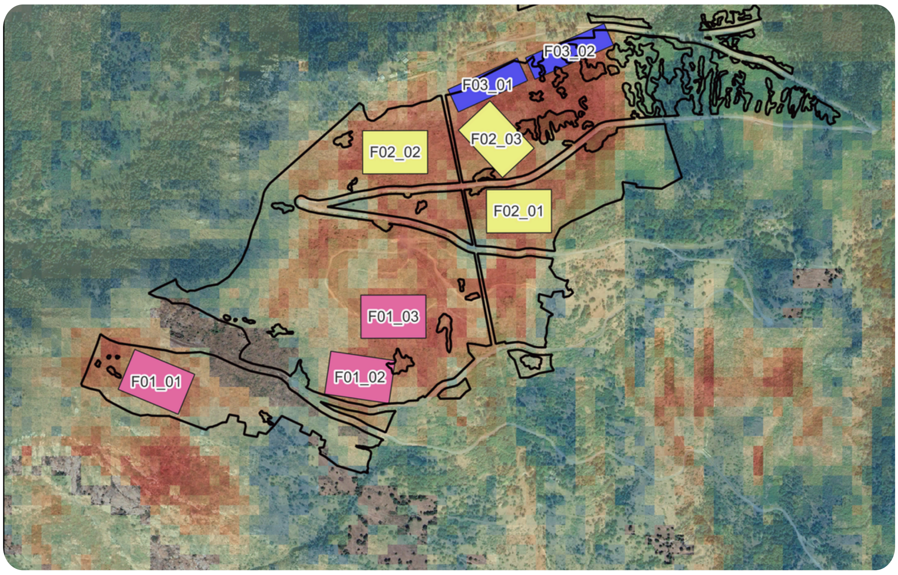
Good practice example

Italy



ARTIFICIAL REGENERATION TO SUPPORT NATURAL DYNAMICS THROUGH APPLIED NUCLEATION AND ECOLOGICAL MODELING

Nicolò Anselmetto, Matteo Garbarino, Raffaella Marzano
Università di Torino (UNITO)

Targeted planting

Natural regeneration is preferable after disturbances, but can be limited by salvage logging, harsh climate or lack of seed sources. In such cases, active restoration through seeding or planting is necessary. Spatial modelling was used to prioritize intervention zones where Scots pine (*Pinus sylvestris*) regeneration is limited, enabling a targeted “applied nucleation” approach.

Models for guidance

- Correlative models of natural regeneration were developed at two Western Alps sites using disturbance, distance to seed trees, topography and species suitability
- Models produced **“presence probability maps”**, where areas with low regeneration were identified and priority seeding polygons were established
- It is recommended to plant in groups near deadwood or under shrubs

Restoration through targeted interventions

Modelling-based prioritization targets low-regeneration areas, improving cost-effectiveness.

Microsite manipulations (necromass, shrub shelter) enhance seedling establishment.

Combining spatial modelling with applied nucleation provides a robust framework for restoration, optimizing resources and resilience.

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For more information visit: https://alpineresilience.org/stories/creating-priority-maps-for-restoring-disturbed-landscapes

Good practice example

Austria

Forests with a direct object-protective function (or primary afforestation sites)

MODELING AND MAPPING PROTECTIVE FORESTS AGAINST ROCKFALL, LANDSLIDES, AND SNOW AVALANCHES

Frank Perzl, Andreas Huber, Laura Saxer, Michaela Teich
Federal Research and Training Centre for Forests, Natural Hazards and Landscape Austria (BFW)

Identifying object-protective forests

The object-protective function of a forest refers to its role in protecting settlements and infrastructure from natural hazards. Identifying such forests involves locating areas, that can reduce the impact of rockfall, landslides or snow avalanches. Specialized modeling tools support their identification and the creation of protective forest maps.

Management support

Protective forest maps created through modeling are valuable tools for protective forest and natural hazard management. They support planning, prioritization and monitoring of silvicultural and other protective measures, as well as providing a basis for further analyses, such as assessing the socioeconomic value of protective forests.

Mapping models

Areas affected by hazards above assets-at-risk must be identified using spatial modelling. Large-scale application requires tools that work with limited data, reliable hazard tracking, and sufficient computing capacity. An empirical topographic mass-movement model was developed for Austrian forest function planning and released as the open-source tool com4FlowPy. Its back-tracking function identifies upslope zones where forests effectively mitigate snow avalanches, rockfall, and shallow landslides, and helps classify them as protective forests or afforestation sites.

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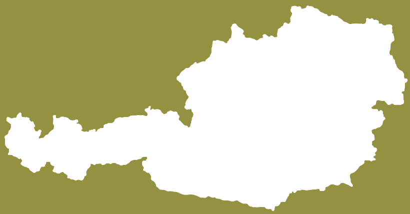
More information at: https://opennhm.org/

Good practice example
Austria



LYING DEADWOOD FOR SNOW AVALANCHE PROTECTION

Leon Bührle, Michaela Teich
Federal Research and Training Centre for Forests, Natural Hazards and Landscape Austria (BFW)

Reducing avalanche release risk

Lying deadwood (e.g., caused by natural disturbances) enhances surface roughness, inhibiting the formation of homogeneous weak layers in the snowpack and reducing the likelihood of snow avalanche release.

Windthrow case studies show that the proposed tool uses **high-resolution drone surveys to deliver spatially explicit assessments of protective effects**, supporting decisions on additional measures and management priorities.

Modeling avalanche release likelihood

The tool assesses the likelihood of avalanche release by combining changes in surface roughness with increasing snow cover, slope, and canopy coverage of remaining standing trees.

Factors shaping protective effectiveness

The protective effect varies depending on deadwood structure, regeneration and slope steepness. However, deadwood generally provides sufficient surface roughness to prevent frequent avalanche release. When deciding whether to retain deadwood for avalanche protection, these factors should be considered.

Protective effect assessment

Drone data enables objective assessment of the protective effect of lying deadwood against snow avalanche release. Lying deadwood generally provides strong protection under frequent snow conditions. Management must carefully balance these benefits for avalanche protection with safety considerations and bark beetle management.

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Good practice example

Austria

THINNING ENHANCES LONG-TERM GROWTH AND STABILITY AFTER ALPINE PASTURE AFFORESTATION

Andrew Giunta, Michaela Teich
Federal Research and Training Centre for Forests, Natural Hazards and Landscape Austria (BFW)

Long-term thinning benefits

This case study examines how elevation, thinning and species composition affect tree growth over 60 years after the afforestation of an alpine pasture in the Sellrain Valley, Tyrol, Austria.

Growth in tree height, diameter at breast height (DBH) and crown dimensions decreased more strongly with elevation, especially during the first 40 years.

Thinning enhanced individual tree growth, but lowered overall stand density and basal area.

Regular thinning significantly improved stand stability and kept mortality below 1%, compared to around 50% in the unthinned plot, demonstrating its importance for maintaining a stable protective forest.

Comparison methods

Tree parameters were measured at ages 25, 30, 38 and 54. Five plots were thinned after each inventory, while one plot remained unthinned.

Basal area, stand density and height-to-diameter ratio were analyzed over time, while growth was compared between thinned and unthinned plots, as well as between pure and mixed-species stands across different elevations.

Key lessons

High planting densities, which increase costs, are unnecessary on sites with adequate moisture. Regular thinning enhances stand stability, reduces mortality and promotes larger DBH values and well-developed crowns.

In this case study, larch (*Larix decidua*) exhibited stronger height and crown growth than Swiss pine (*Pinus cembra*), although DBH remained similar between the species.

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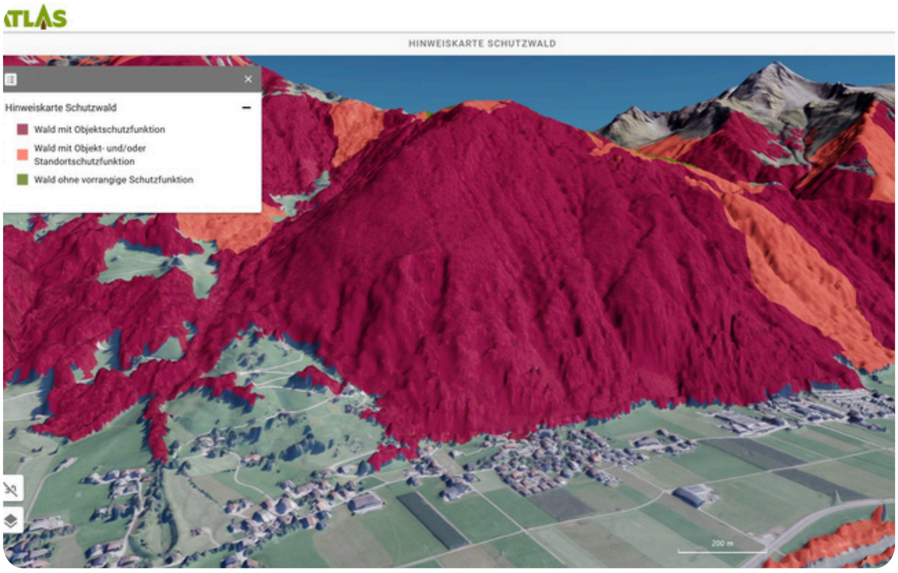
For more information visit:
https://www.bfw.gv.at/bergauf-aufforstung-klimawandel-und-biodiversitaet-im-alpinen-raum/

Good practice example

Austria



WALDATLAS: AUSTRIA'S HUB FOR GEODATA ON PROTECTIVE FORESTS AND NATURAL HAZARDS

Alexander Starsich[1], Frank Perzl[2] , Michaela Teich[2]

1 Federal Ministry of Agriculture, Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK), 2 Federal Research and Training Centre for Forests, Natural Hazards and Landscape Austria (BFW)

What is WALDATLAS?

WALDATLAS is Austria's **interactive digital forest spatial - information system** and a central nationwide platform providing quality-checked, freely available spatial data on forests, natural hazards and biodiversity.

It includes geospatial information on protective forests, such as an indication map of forest protective functions and is provided by the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK).

Interactive mapping and analysis tools

WALDATLAS is a web-based map service for computers and mobile devices, offering interactive tools and about 40 regularly updated thematic maps with base layers such as topography, orthophotos, geology and cadastral data.

It provides geodata and metadata by coordinate selection and includes Austria's first 3D view with thematic overlays for realistic visualization of terrain, forests, hazard zones and object-protective forests.

Geodata for stakeholders

The platform serves the public and key stakeholders by providing high-quality geospatial information. Some datasets, including the protective forest indication map, are modelled or remote-sensing based and validated by regional forestry and natural-hazard authorities. These geodata support analyses of protective forests, natural hazards, biodiversity, and BMLUK publications.

AUSTRIAN RESEARCH CENTRE FOR FORESTS

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Federal Ministry Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management Republic of Austria

For more information visit: https://waldatlas.at/

Good practice example

Switzerland

NAIS: SWISS GUIDELINES FOR OPTIMIZED MANAGEMENT IN PROTECTION FORESTS

Peter Bebi[1] and Christine Moos[2]

1 Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), 2 Bern University of Applied Sciences (HAFL)

NaiS Guidelines (Sustainability in Protective Forests) provide a comprehensive framework for sustainable management of protective forests in Switzerland.

They evaluate forest condition, protective function and maintenance needs, using standardized criteria, enabling prioritization of interventions and efficient resource allocation for long-term hazard protection.

NaiS is widely used, practical, scientifically grounded tool for forest management and hazard mitigation.

Protective forests assessments

- **Protective forest stands and hazards** (e.g. avalanches, rockfall, shallow landslides) are identified .
- **Forest condition is assessed using NaiS criteria and reference profiles**, focusing on structure, species composition, stability, regeneration and site conditions.
- **Comparison with NaiS requirements defines management needs**, and follow-up assessments monitor the maintenance or improvement of protective functions.

Mapping disturbance risks

NaiS provides a standardized overview of whether protective forests meet target conditions. Comparison with reference profiles identifies stands with reduced protective performance and prioritizes them for intervention. NaiS is continuously developed, including climate-adapted tools (e.g., NaiS Form 2) integrating climate change impacts.

From research to practical application

NaiS provides a standardized, decision-support framework that links forest condition to prioritized management actions, enabling efficient and climate-adaptive protective forest management.

For more information visit:
https://www.bafu.admin.ch/de/nais

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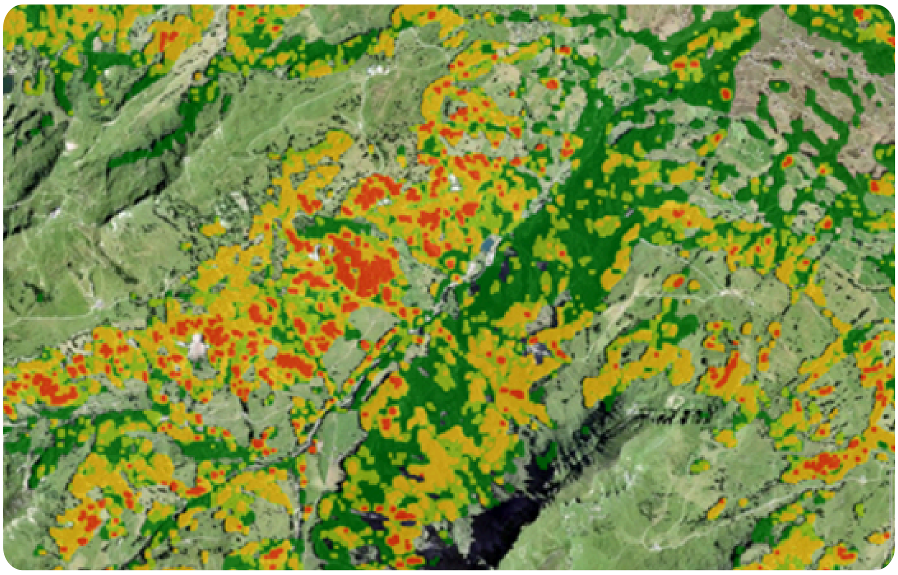
Switzerland



PRIORITIZING MANAGEMENT INTERVENTION OF HOMOGENOUS, SPRUCE-DOMINATED MOUNTAIN FORESTS

Peter Bebi and Leon Bührle

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

Prioritizing management criteria

With limited resources, forest interventions must be transparently prioritized to strengthen protective forests against disturbances such as bark beetle outbreaks by integrating stand vulnerability, ecosystem service importance, resilience and recovery potential and technical-economic feasibility.

Method development

- **Forest structure and site data analyzed** with expert models produced predisposition maps for windthrow, snow breakage and bark beetles.
- **Natural hazard risk assessments quantified** protective effects against avalanches and rockfall and economic value of risk reduction.
- **Potential loss of protective function** under severe disturbance scenarios was estimated. Outputs were combined to generate prioritization maps.

Future application

The framework is expanding in Swiss cantons and is transferable to other mountain regions, supporting operational planning, intervention evaluation, protective forest modelling, disturbance scenario analysis and future integration into an interactive decision-support system.

Mapping disturbance risks

Predisposition maps for windthrow, bark beetles and snow breakage are found to be useful in mountain spruce forests management. Nationwide ALS data captured fine-scale terrain patterns and showed high accuracy for windthrow and bark beetle predisposition, validated by over 140 field assessments. Forest structure was most influential, while snow breakage results need refinement.

For more information visit:
https://www.wsl.ch/en/projects/mountex/

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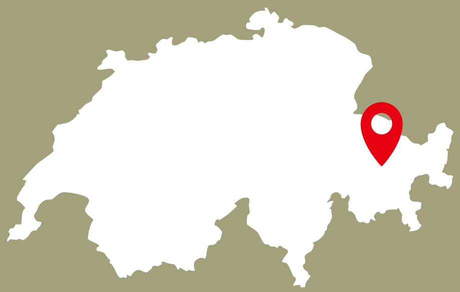

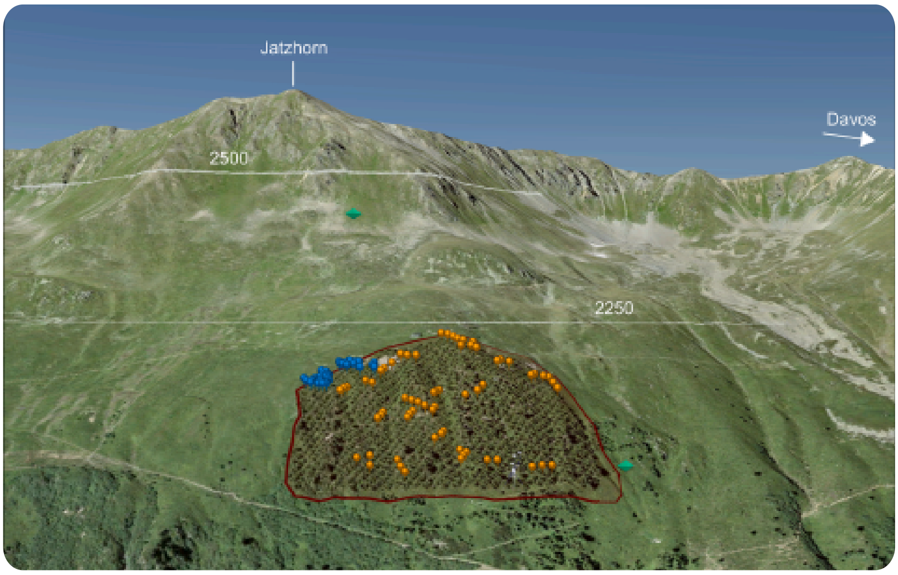

LESSONS FROM AFFORESTATIONS NEAR TREELINE

Peter Bebi

Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

Treeline afforestation

Over the past 50 years, long-term studies near the treeline in Davos, Switzerland, have improved understanding of treeline dynamics and enhanced afforestation methods for high-elevation protective forests against natural hazards.

Planting trials

The main Stillberg experiment began in 1975, with planting of 92,000 trees of three species in a systematic design. Additional trials were established at other treeline sites. Tree height, mortality and major damage were periodically recorded and analyzed. The sites were also used for ecological experiments assessing climate-change impacts on the treeline.

Long-term treeline research

The Stillberg experiment has provided nearly **50 years of insights into treeline dynamics** and high-elevation afforestation.

Early tree growth and mortality are mainly controlled by microtopography, snow cover, wind exposure and soil moisture, while later development is shaped by species-specific and mechanical constraints.

Nutrients, snow regimes, and competition drive long-term responses to changing conditions, **highlighting Stillberg's value for assessing protective forest potential under climate change**.

Key lessons

Afforestation above the treeline can provide lasting hazard protection when adapted to site conditions, but long-term resilience depends on structural and species diversity—highlighting the importance of long-term studies like Stillberg for managing changing mountain ecosystems.

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For more information visit: https://www.slf.ch/en/about-the-slf/instrumented-field-sites-and-laboratories/mountain-ecosystem-research-sites/stillberg-afforestation-research/

Good practice example

Switzerland

INFLUENCE OF GAP SIZE ON REGENERATION OF LIGHT DEMANDING SPECIES

Peter Bebi[1] and Christine Moos[2]

1 Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), 2 Bern University of Applied Sciences (HAFL)

Gap size effect on regeneration

Case study in the Bernice Alps examined the influence of gap size on regeneration density of light-demanding species. The study underlines the importance of considering local site conditions to successfully promote species diversity in the face of climate change.

Tracking regeneration

In this study, regeneration was sampled in 221 plots at 23 sites in the Bernice Alps. All sites were in the montane elevation zone. Density and height of regeneration was analyzed with respect to gap size, forest cover, concurrence vegetation, browsing intensity and topographical characteristics. The method follows other case studies in Switzerland.

Limits to regeneration in large gaps

The study revealed a negative or insignificant relationship between regeneration density and gap size. In particular, the **number of light demanding species was not positively influenced by an increasing gap size.**

A plausible explanation for this finding was the **high vegetation concurrence** at a majority of the sites.

Additionally, damages from browsing were frequent, but not limiting for regeneration.

Matching gap size to site conditions

Although larger gaps can be efficient in promoting light demanding, climate-adapted species, this study showed, that this might not be successful at all sites. Various factors, such as vegetation concurrence or browsing pressure have to be considered for effective interventions in protective forests.

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Good practice example

Switzerland

"HYBRID APPROACHES" AS EFFICIENT PROTECTIVE MEASURE IN THE FACE OF CLIMATE CHANGE

Christine Moos
Bern University of Applied Sciences (HAFL)

Structural support

Case study took place in the Swiss Western Alps and was focused on the economic efficiency of protective forests and structural measures combination against rockfall. The study evidenced, that hybrid solutions are efficient alternatives and the protection goal cannot be achieved with the forest alone.

Assessment methods

- **Derivation of future forest scenarios** based on process-based modeling (TreeMig model)
- **Quantification of rockfall risk reduction** for different forest scenarios based on 3D rockfall simulations
- **Cost-Benefit Analysis**

Conclusion

Key drivers of growth and survival change during stand development. Maintaining structural, age and species diversity is essential for climate adaptation and resilience to extreme events.

Cost-benefit of hybrid protection systems

Protective forest management can often replace technical measures, but climate change may reduce its effectiveness.

Hybrid solutions combining forests and technical measures, such as in the Chillon case study, provide effective and economically viable risk reduction, even under severe climate change scenarios.

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SLOVENIA

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Research in Jelovica plateau, Slovenia

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