Interreg
Co-funded by the European Union
Alpine Space

MOSAIC

Protective forest management in the Alps: an illustrated guide

Interreg
Co-funded by the European Union
Alpine Space
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

Title: Protective forest management in the Alps: an illustrated guide
Publisher: Slovenian Forest Service (SFS)
Place of publication: Ljubljana, Slovenia
Year: 2026
Version: Final (digital edition)
Available at: https://dirros.openscience.si/IzpisGradiva.php?id=30407

Editors: Kristina Sever and Andrej Breznikar (Slovenian Forest Service)
Graphic design and illustrations: Lara Kastelic s.p.
Production editors: Magdalena Cholkova and Eva Dušak (Slovenian Forest Service)

Authors of Chapters 1, 2, 3 and 5:
Kristina Sever[1], Nicolò Anselmetto[4], Tommaso Baggio[6], Frédéric Berger[7], Magdalena Cholkova[1], Matteo Garbarino[4], Matjaž Guček[1], Milan Kobal[2], Emanuele Lingua[6], Davide Marangon[6], Raffaella Marzano[4], Aleš Poljanec[1], Laura Saxer[5], Michaela Teich[5], Andrej Breznikar[1]

Authors of Chapter 4 organised in alphabetical order:
Nicolò Anselmetto[4], Tommaso Baggio[6], Peter Bebi[8], Frédéric Berger[7], Andrej Breznikar[1], Leon Bührle[5], Magdalena Cholkova[1], Matteo Garbarino[4], Andrew Giunta[5], Markus Graf[9], Matjaž Guček[1], Andreas Huber[5], Michael Kirchner[3], Matija Klopčič[2], Milan Kobal[2], Stane Kunej[1], Emanuele Lingua[6], Davide Marangon[6], Raffaella Marzano[4], Nikolina Mencin[2], Christine Moos[9], Andreja Nève Repe[1], Petia Nikolova[8], Frank Perzl[5], Aleš Poljanec[1], Boris Rantaša[11], Paul Richter[6], Laura Saxer[5], Tabea Schaefers[3], Andreas Schuck[10], Kristina Sever[1], Alexander Starsich[12], Michaela Teich[5], Jean-Jacques Thormann[9], Sergey Zudin[10]

Affiliations:
1. Slovenian Forest Service (SFS), Slovenia
2. University of Ljubljana (UL), Slovenia
3. The University of Göttingen (UGOE), Germany
4. University of Turin (UNITO), Italy
5. Austrian Research Centre for Forests (BFW), Austria
6. University of Padua (UNIPD), Italy
7. National Research Institute for Agriculture, Food and Environment (INRAE), France
8. Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Switzerland
9. Bern University of Applied Sciences (HAFL), Switzerland
10. European Forest Institute (EFI), Finland
11. Slovenian Forestry Institute (SFI), Slovenia
12. Federal Ministry of Agriculture, Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK), Austria

Funding statement: This publication has been developed within the MOSAIC project, funded by the Interreg Alpine Space Programme of the European Union.

Kataložni zapis o publikaciji (CIP) pripravili v Narodni in univerzitetni knjižnici v Ljubljani
COBISS.SI-ID 282604547
ISBN 978-961-6605-65-6 (PDF)

MOSAIC - Managing protective forest facing climate change compound events

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

Therefore, the MOSAIC project focuses on hazard-resilient and sustainable protective forest management that addresses the multiple dimensions of climate change, 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, as well as to model Alpine climate-related disaster trends and the protective effects of forests. The project partners also 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

Based on the results of other project activities and the Forest Living Labs, a collection of best practice examples and silvicultural measures for forest resilience and climate change adaptation is presented using an innovative approach with illustrations and infographics.

Table of Contents

1. Introduction

Mountain forests play a vital role in protecting people, infrastructure and livelihoods, as well as forest stands and sites themselves, from natural hazards. These protective forests are defined as forests whose one of the main functions is to protect society and assets from hazards such as snow avalanches, rockfall, landslides, debris flows, floods, torrents, 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 characteristics such as structure, species composition, regeneration and long-term ecological stability, as well as on the type and intensity of natural hazard. 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 (Bebi et al., 2017). 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 compound processes (including cascading or domino effects) can severely affect forests that lack resilience, reducing their protective effect when it is needed most (Moos et al., 2023).

For these reasons, protective forests are a key example of a forest-based solution, a specific type of nature-based solution, for disaster risk reduction and climate change adaptation (Rey et al., 2024). When sustainably managed, they provide a no-regrets 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 and adaptive forest management within climate action planning, linking ecosystem-based disaster risk reduction measures, nature-based solutions, and sustainable forestry.

The work builds on results from the MOSAIC project, as well as knowledge generated in Forest Living Labs (FLLs), where researchers, 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 real forest 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, fostering a shared understanding of adaptive forest 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 also under the uncertain and changing conditions of tomorrow.

2. Silvicultural measures in protective forests

An appropriately structured forest can effectively mitigate natural hazards such as avalanches, rockfall, landslides, debris flows, torrents, 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 (Teich et al., 2022). The protective effect of forests, however, is not constant; it changes over time. Their protective effect depends on forest structure, species composition, vitality, and stability, all of which are shaped by both natural dynamics and forest management measures. Both living and dead trees (logs and snags) present obstacles that stop or slow down falling rocks and increase terrain roughness (Ringenbach et al., 2023). This is crucial to prevent snow avalanche release and can also help reduce slope movements, such as landslides, rock slides, and mass flows (debris and mud).

Silvicultural measures are a key instrument for ensuring that protective forests maintain and enhance their functionality over time (Diaci, 2012). 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 risks (Motta and Haudemand, 2000). These risks are 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 canopy structures contribute to enhanced resistance and resilience against disturbances and slope related processes. 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 effect (Diaci, 2012; Kajdiž et.al., 2015; Vilhar, 2024).

Furthermore, active management enables adaptive responses to changing environmental conditions. Adaptive forest management, 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 (Spadoni et al., 2026).

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 effects. Special emphasis is placed on their 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

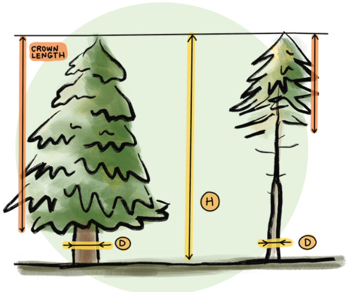
Forest stand stability is the forest's ability to **withstand natural disturbances** (e.g. wind, snow, pests, rockfall). It depends on the mechanical and ecological stability of **individual trees** and the overall **structural resilience of the stand.**

Assessment

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

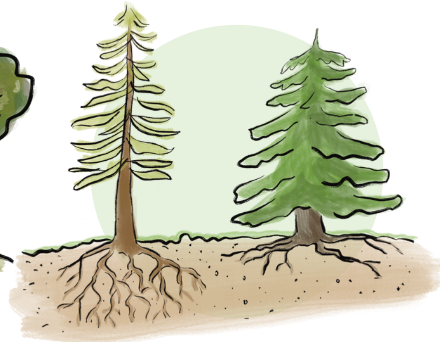
Stem inclination

Height-to-diameter ratio (HDR) and crown ratio (CR)



Crown asymmetry

Root system development



Importance for protective forests

Stand stability is essential in protective forests and plays a crucial role in maintaining their protective effect during unpredictable natural events.

Implementation requirements

Preserving and enhancing **optimal stand stability requires targeted silvicultural measures at all development stages.** These include thinning to improve structure and diversity, removing old or heavy trees where applicable, ensuring timely natural regeneration, and avoiding overly large gaps in the direction of the slope to reduce the risk of erosion, snow avalanches, and rockfall.

Threshold values

Optimal stand stability can be achieved through a high proportion of trees with:

- HDR less than 80
  For a tree height of 25 m, the optimal DBH would be 31 cm or more.
- Optimal crown ratio
  The live crown length should be at least one-third of the total tree height.
- No or low stem inclination
- Symmetrical crowns
- Deep root systems (e.g. larch)

Interreg Alpine Space
Co-funded by the European Union
MOSAIC

IMPROVING TREE SPECIES COMPOSITION UNDER CLIMATE CHANGE

Tree species composition refers to the **proportion and distribution of different tree species** within a forest stand, indicaiting how mixed or uniform a stand is in terms of species diversity. Appropriate tree species composition is crucial for forest stability, especially in protective forests, as it enhances resilience to disturbances and climate change.

Assessment

Tree species composition can be assessed using the following indicators:

- Tree species mixture
- Naturalness of tree species composition
- Root system development

Tree species composition indicators for snow avalanche protection:

- Crown cover

  The optimal stand crown cover is above 70%, while values below 30% are considered critical.
- Share of evergreen conifers

  A high proportion of evergreen conifers should be ensured, ideally around 70%.

Importance for protective forests

Deep-rooted tree species stabilize slopes, reducing landslide risk. Structural diversity enhances the forest's capacity to intercept and slow rockfall, while canopy cover moderates snow accumulation to decrease snow avalanche risk. Using site-adapted tree species ensures long-term forest stability and effective hazard mitigation in a changing environment.

Implementation requirements

Selection of resistant tree species through single-tree harvesting and controlled mixed-growth management is recommended. Retention of desired tree species is needed to guide stand development and preserve valuable mixed species for long-term regeneration. Enrichment planting should be used to enhance species diversity, minimize disturbance and maintain continuous forest cover. Seedlings should be protected from browsing damage through appropriate browsing protection. Management should aim for **uneven-aged forest structures.**

OPTIMISING SPATIAL DISTRIBUTION OF TREES

Spatial distribution of trees through their **position, arrangement,** and **density** affects terrain stabilization and the forest's ability to mitigate slope-related gravitational processes (e.g. rockfall).

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

Importance for protective forests

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

Implementation requirements

Optimal spatial distribution of trees 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 management objectives.

Interreg Alpine Space
Co-funded by the European Union
MOSAIC

Learn more in the MOSAIC WebGIS Atlas

FOREST GAPS MANAGEMENT

Gaps are areas in a forest where the **forest stand is open** for certain reasons (e.g. logging, tree mortality, 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 distribution of trees** together with the **relative crown area** enables the **identification of areas without forest cover**, as well as a precise assessment of the **size and orientation of forest gaps.**

Threshold values

Large gaps in the slope direction, exceeding **1–2 times the height** of surrounding trees, should be avoided.

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 effect in forests exposed to slope-related gravitational hazards.

Implementation requirements

Gaps are essential structures for stand regeneration, but if they are too big, the risk of natural hazards can dramatically increase. Management should avoid creation of large gaps, especially in the direction of the slope. **An irregular patch cutting pattern** can help achieve this.

NATURAL REGENERATION MANAGEMENT

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

Assessment

Key indicators include:

- Presence of **natural regeneration**
- Seedling **species**, **vitality,** and **density**
- **Naturalness** of tree species composition
- **Constant forest cover**
- **Impact of ungulate herbivores**

Importance for protective forests

Natural regeneration replaces aging trees with individuals adapted to local conditions, maintaining species composition, structural diversity and stand stability. Root systems suited to microsites enhance slope reinforcement and long-term resilience, while genetic diversity strengthens adaptive capacity under climate change and ensures continuous forest cover for hazard mitigation.

Implementation requirements

To achieve optimal natural regeneration, mature trees should be selectively removed to gradually increase light and create small gaps, that stimulate seed germination, while minimizing soil disturbance. Mixed species should be retained during harvesting to ensure seed availability for future regeneration. Young seedlings should be protected during felling and extraction operations and from browsing, which may require active ungulate management. In areas lacking natural regeneration, small-group selection is recommended, while enrichment planting should be applied only where necessary.

Learn more in the MOSAIC WebGIS Atlas

ACTIVE RESTORATION THROUGH PLANTING AND SEEDING

Active restoration is needed when natural regeneration is limited, slow or insufficient or when climate change reduces ecosystem resilience. This involves **planting** or **seeding** to accelerate forest recovery, promote target tree species, maintain genetic diversity and support ecosystem dynamics and enhance the protective effect of forests.

Assessment

Effectiveness can be evaluated through recruitment rates:

- **Seedling emergence**
- **Seedling survival and growth**

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

- **Seedling density**
- **Species composition**
- **Spatial arrangement**

Importance for protective forests

Regeneration ensures continuous protective effect. Rapid establishment of seedlings stabilizes stands and slopes, while seeding promotes root development. Young trees growing in the presence of deadwood increase surface roughness, thereby reducing rockfall and snow avalanche impact. Active restoration also enhances species diversity and climate resilience.

Implementation requirements

Successful outcomes require careful timing, site, species and provenance selection. Seedlings should have well-developed roots and balanced root/shoot ratios, while browsing should be controlled. Deadwood must be retained and microsites near deadwood or sheltered areas should be favored, in order to provide seedlings protection and hazard risk reduction. Hydrogels can improve survival on steep or dry slopes, while monitoring is essential to guide adaptive management and maintain protective effect.

INTEGRATED DEADWOOD MANAGEMENT

Lying deadwood **increases surface roughness, enhances protection against gravitational hazards** (e.g. snow avalanches) and **creates** favorable **microsites** for **seedlings** by moderating temperature, moisture, and browsing. It supports biodiversity by providing habitat and resources for forest organisms.

Assessment

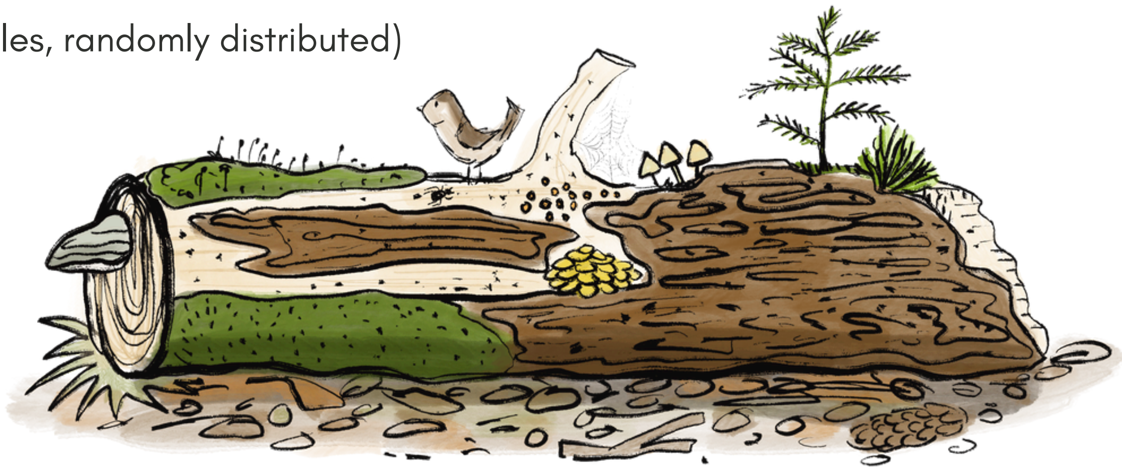
The indicators that can be used are:

- **Type of deadwood** (e.g. snags, logs, stumps)
- **Decay class**
- **Mass and volume**
- **Spatial distribution** (e.g. piles, randomly distributed)

Threshold values

Recommended threshold values:

- **At least 2 logs per 10 m**
  In gaps larger than 20 m, the log diameter should exceed the expected rock diameter.
- Minimum **stump height 1.3 m**



Importance for protective forests

Deadwood slows and deflects rocks, thereby mitigating rockfall. In avalanche-prone areas, it increases surface roughness, stabilizes the snowpack, and reduces the risk of glide-snow, slab, and loose-snow avalanches. Retaining deadwood after disturbances helps maintain protective effect, supports regeneration, and sustains ecosystem diversity.

Implementation requirements

Deadwood management must balance ecological benefits with safety. Retention near roads, trails or settlements may require selective removal or stabilization. Damaged or hazardous trees can be cut and repositioned to maintain safety while preserving ecological functions, a practice referred to as **deadwood manipulation**.

3. Biotechnical measures in protective forests

In situations where forest cover has been removed or severely degraded by disturbances such as windthrow, wildfire, or bark beetle outbreaks, as well as erosion or slope-related processes, biotechnical measures are often required to stabilise the site and support the re-establishment of vegetation. These measures combine biological materials, such as wood and living plant material, with simple technical elements to stabilise slopes, reduce surface erosion and shallow soil movement, and support forest regeneration (Dorren, 2022).

Compared to purely technical solutions, biotechnical measures can be less invasive and more cost-effective, depending on site conditions. Their main limitation is the limited durability of materials such as wood, which are subject to natural decay (Dorren, 2022). However, these measures are generally intended to provide temporary stabilisation until vegetation becomes established and the slope regains its stability and protective effect.

The infographics presented in this chapter provide a concise and practical overview of key biotechnical measures used in protective forests, highlighting their main characteristics, application conditions, and contributions to slope stabilisation and hazard mitigation. Particular emphasis is placed on their role in supporting site recovery and the re-establishment of vegetation, thereby helping to restore the protective effect of forests under changing environmental conditions.

However, in cases where the protective effect 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 (Dorren, 2022). In such situations, biotechnical measures should be understood as transitional measures, that support site stabilisation and vegetation recovery, while technical measures provide immediate protection where needed.

SLOPE STABILISATION WITH CUTTINGS AND SEEDLINGS

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

Cuttings are living sections of branches, typically up to 2 cm in diameter and 30 cm in length.

Importance for protective forests

- Due to their strong vegetative capacity, cuttings, especially **willow species (*Salix* spp.)**, develop roots and shoots from dormant buds, thereby binding soil particles and preventing surface erosion.

- Naturally occurring plant species, that are already adapted to the site conditions should be chosen for wildings, for example, **European larch** (***Larix decidua***) in the Alps, due to its deep root system.

Implementation requirements

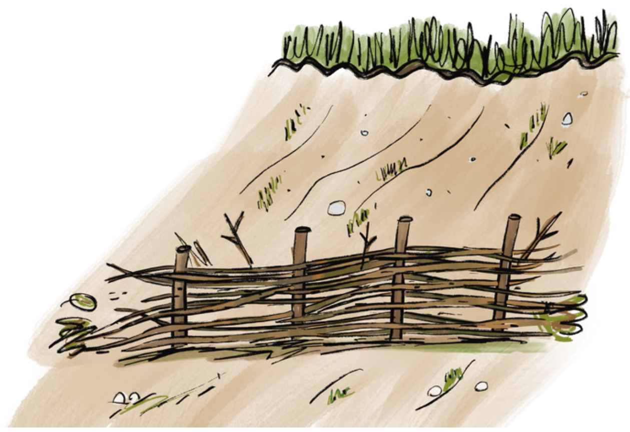
Cuttings, thumb-thick branches cut to appropriate length, are planted at an angle with buds facing upward, at a density of approximately 1 per m^2 in early spring, to promote strong root development.

Wildings should be collected from areas near erosion hotspots, kept out of direct sunlight, and planted under moist conditions (in autumn or spring) to minimize root damage and ensure successful establishment.

SLOPE STABILISATION WITH FASCINES AND WATTLE FENCES

Fascines are bundles of branches from pioneer tree species, mainly willows (*Salix* spp.) and alders (*Alnus* spp.), tied together and secured with wooden (usually willow) stakes.

Wattle fences consist of intertwined branches from pioneer tree species, mainly willows (*Salix* spp.) and alders (*Alnus* spp.), 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 it, depositing forest debris that forms a new soil layer, while preventing particle movement and erosion along the bank, by acting as a physical barrier.

Implementation requirements

- **Fascines** are bundles of willow branches (30–40 cm in diameter and 4 m long) with buds facing the sun. They are laid across slopes at a slight angle, secured with stakes, embedded in the soil, and spaced 2–3 m apart. The best time for installation is early spring.
- **Wattle fences** are constructed using stakes approximately 10 cm in diameter, placed at 1 m intervals, with thin branches woven to a height of 50 cm, using a basket-weaving technique. The branches can be soaked to increase flexibility, after which a layer of mulch can be applied on top.

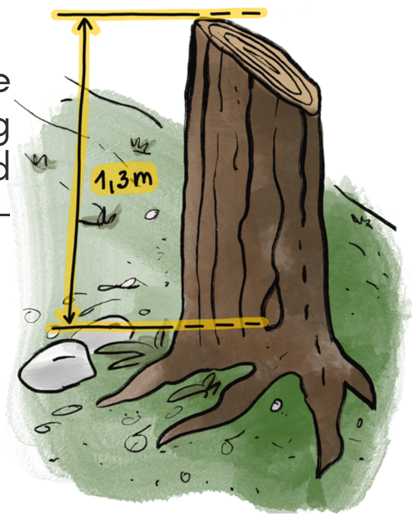
STUMP MANAGEMENT FOR FOREST PROTECTIVE FUNCTION

In order to improve the protective effect of forests on steep slopes after harvesting or salvage logging, several **stump management techniques** can be applied, including the retention of:

- High stumps at 1,3 m
- Stumps cut above the existing injuries
- Low stumps

Importance for protective forests

High stumps (1,3 m) help maintain the protective effect of forest after harvesting by acting as surface roughness and physical barriers, thereby reducing slope-related processes.



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

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

LOGS ON SLOPES: ENHANCING FOREST PROTECTIVE FUNCTION

To enhance the protective effect of forests on steep slopes after harvesting or salvage logging, the following log management techniques can be applied.

Logs positioned perpendicular to the slope act as barriers, slowing or redirecting rocks and supporting natural regeneration.

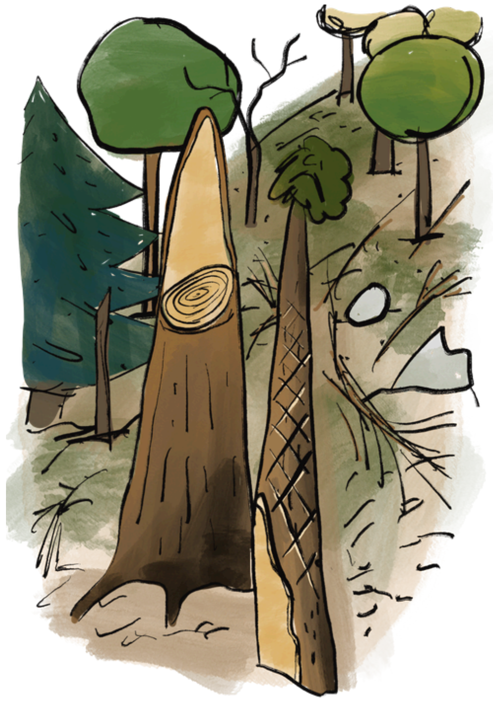
The positioning depends on **slope inclination**:

≤ **25°** → logs positioned **perpendicular** to the slope direction

> **25°** → logs positioned at an angle of **70°** to the slope direction

For increased stability, **logs are anchored** to stumps or standing trees. They slow down and stop rocks more effectively than unanchored logs.

Alpine cut is a specialised directional felling technique used on steep slopes. It involves retaining high stumps and positioning logs, so that they remain anchored behind the stump of the felled tree, while also leaving piles of branches and logging residues in place, to slow falling rocks and support natural regeneration.



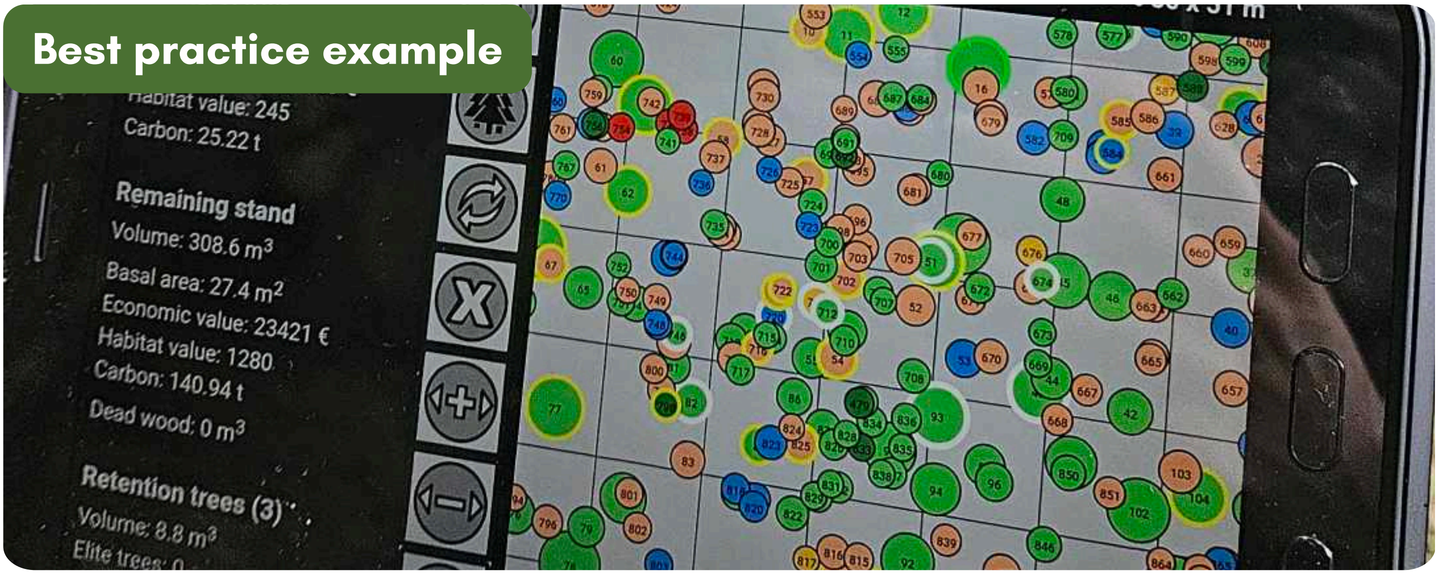
Functional lifespan of logs in relation to wood decay:
broadleaves → **5 - 10 years**
conifers → **8 - 15 years**

4. Best practice examples, research 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, Italy, and Switzerland. These contributions illustrate diverse approaches to managing protective forests and mitigating natural hazard risks under varying environmental, socio-economic, and institutional conditions across the Alpine region.

The examples are presented as 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.

Best practice example



MARTELOSCOPE AS AN EDUCATIONAL TOOL FOR PROTECTIVE FOREST MANAGEMENT

Kristina Sever[1], Andrej Breznikar[1], Magdalena Cholkova[1], Sergey Zudin[2], Andreas Schuck[2]
1 Slovenian Forest Service (SFS), 2 European Forest Institute (EFI)

What are Marteloscopes?

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

Protective module upgrade

The MOSAIC project, in collaboration with the European Forest Institute, upgraded the I+ Trainer software for virtual tree selection by adding a protective forest module, including protective forest indicators and indexes for rockfall, snow avalanches, and shallow landslides.

Importance for protective forest management

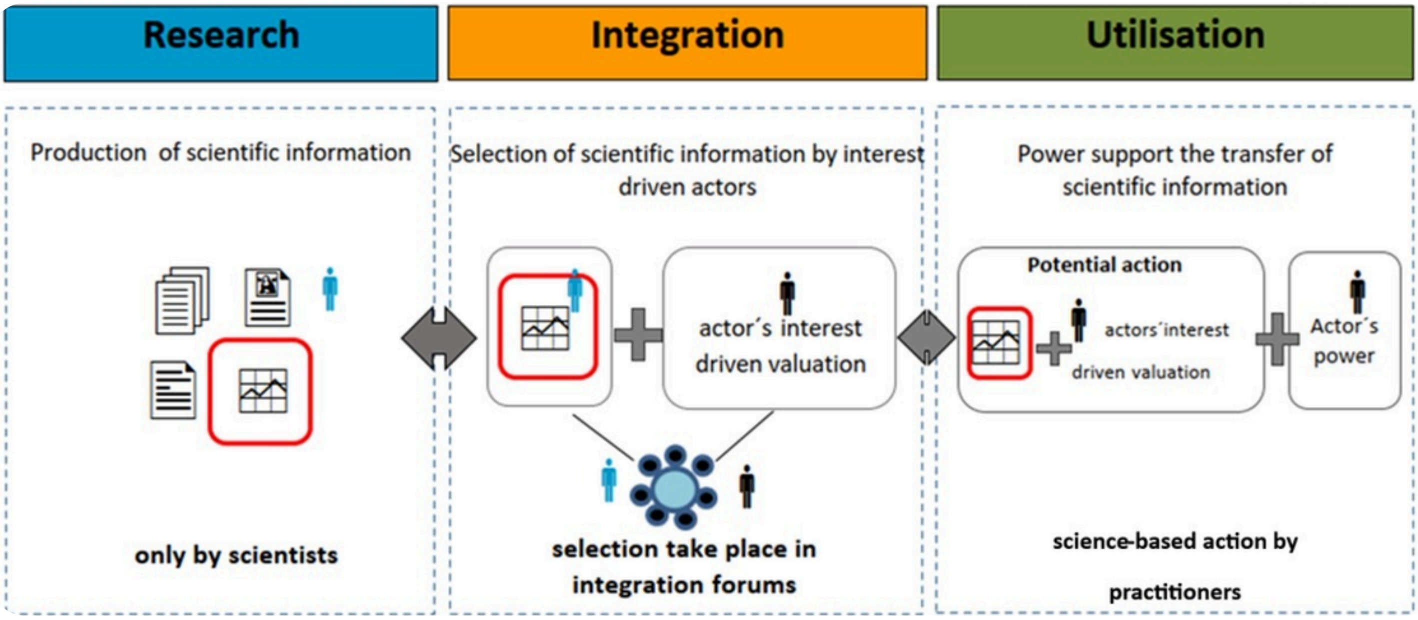
Protective forest management focuses on maintaining stand stability and preventing slope related processes such as landslides, avalanches, or rockfall. Marteloscopes help train forestry professionals to apply appropriate silvicultural measures in these sensitive areas.

Protective forest indicators used in I+ Trainer

- Height/diameter ratio
- Root system
- Crown asymmetry
- Stand structure
- Crown cower
- Regeneration
- Gaps
- Tree distribution
- Stand density
- Stand basal area

For more information visit: Marteloscopes

Interreg Co-funded by the European Union
Alpine Space
MOSAIC
EFI



MAKING RESEARCH WORK: INTEGRATION FORUMS FOR EFFECTIVE NATURAL HAZARD MANAGEMENT

Tabea Schaefers and Michael Kirchner
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 that research outcomes are relevant and actionable.

Connecting research and practice

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

Putting knowledge into practice

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

For more information visit:
- Science makes the world go round
- Research-Integration-Utilisation (RIU) model

Research site
Slovenia

POST WINDTHROW NATURAL REGENERATION CAN PROVIDE MORE RESILIENT FORESTS

Research in Jelovica plateau, Slovenia

Aleš Poljanec[1,2], Kristina Sever[1], Andreja Nève Repe[1], Matija Klopčič[2]
1 Slovenian Forest Service (SFS), 2 University of Ljubljana (UL)

After the storm

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

Tracking nature's response

Regeneration on 125 ha was monitored using 81 permanent plots. Field surveys conduceted in 2008, 2011, 2017, and 2025 recorded species composition, height classes, browsing damage, 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 effects like soil stabilization, biodiversity, and ecosystem recovery. Early tending and thinning can further improve forest stand structure.

Mountain mixed forests successfully regenerated within two decades after a disturbance

Regeneration density was high and sufficient, rising from **8.380 in 2008 to 12.400 seedlings per ha in 2025**, with strong spatial variability.

Tree species composition shifted from initial Norway spruce dominance to a more diverse mixture, with **increasing broadleaves** and **late-successional species** over time.

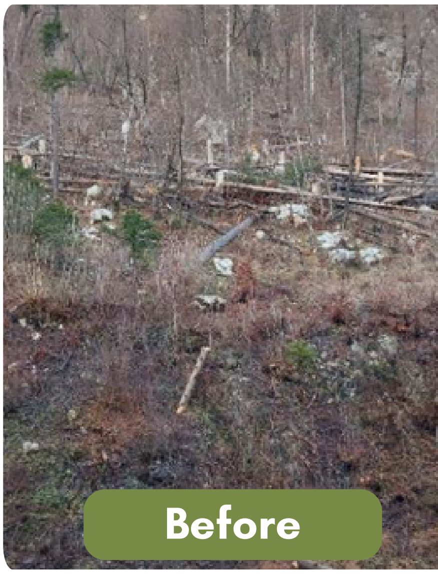
The regeneration height structure shifted from seedling dominance in the height class below 50 cm in 2008 to a **stable and continuous distribution across all height classes** by 2025.

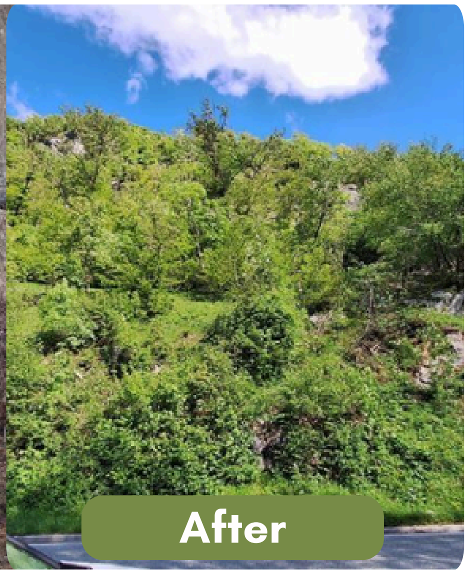
Ungulate browsing has increased over time, strongly affecting seedlings below 130 cm and selectively damaging sycamore maple and rowan, thereby influencing future species composition.

Interreg Alpine Space Co-funded by the European Union
MOSAIC
Zavod za gozdove Slovenije
Slovenian Forest Service
BF UNIVERZA V LJUBLJANI Biotehniška fakulteta

Best practice example

Slovenia





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

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

Hazard risks

In the protective spruce forest above the main road in Soteska near Bohinj, designated as a MOSAIC Forest Living Lab, a bark beetle outbreak in unmanaged stands led to frequent tree falls and rockfall events.

Slope stabilisation

A salvage logging, complemented by biotechnical measures, was carried out to stabilise the area and protect the road from rockfall. Following the intervention, natural regeneration progressed successfully, further contributing to the effective protection of both the road and the forest stand. The applied biotechnical measures included **high stumps (1.3 m)** and **logs anchored behind the tree stumps** at a 70° angle to the fall line.

Directional felling

To position logs at the correct angle, directional felling must be performed. In directional felling, it is crucial that trees are healthy at the time of cutting. If decay has already advanced, directional felling becomes unreliable, as trees may fall unpredictably and potentially endanger the infrastructure below.

Nature-based protection

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

The sanitary felling, followed by a retention of high stumps and anchored logs, completely prevented falling rocks from reaching the road. The stand regenerated naturally, demonstrating that nature-based solutions can effectively restore both slope stability and protective effect.

Furthermore, this nature-based approach proved significantly **more cost-efficient than conventional technical protective measures.**

Zavod za gozdove Slovenije
Slovenian Forest Service
Interreg Co-funded by the European Union
Alpine Space
MOSAIC

Research site

Slovenia

INNOVATIVE FOREST RESTORATION IN FIRE-AFFECTED AREAS

Research in Karst region, Slovenia

Magdalena Cholkova[1], Boris Rantaša[2], Kristina Sever[1], Andrej Breznikar[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	Expected results	Protective forest benefits
Planting seedlings treated with **hydrogels and mycorrhiza.**	Improved **seedling establishment, survival,** and **growth.**	Enhanced **erosion resistance** and **long-term protective effect.**
Drone seeding with seed bombs.	Rapid area coverage and **high germination.**	Reforestation of **inaccessible terrain.**
Enrichment planting using authochtonous broadleaves.	Increased species **diversity**.	Forest ecosystem **resilience** and **adaptability.**

Interreg Alpine Space
Co-funded by the European Union
MOSAIC

Zavod za gozdove Slovenije
Slovenian Forest Service

GOZDARSKI INŠTITUT SLOVENIJE
SLOVENIAN FORESTRY INSTITUTE

For more information visit: MOSAIC WebGIS Atlas

Research site

Slovenia

SNOW INTERCEPTION IN MONTANE SPRUCE FORESTS

Nikolina Mencin[1], Frédéric Berger[2], Milan Kobal[1]
1 Univeristy of Ljubljana (UL), 2 National Research Institute for Agriculture, Food and the Environment (INRAE)

Importance of snow interception

Snowfall interception by forest canopies regulates snow distribution in mountain forests by controlling how much snow is retained in the canopy versus how much reaches the ground. It shapes accumulation and melt patterns, influencing soil moisture, seedling survival, and timing of growing season. In protective forests, canopy-snow interactions affect snow loading, unloading, and redistribution, thereby influencing forest stability and mitigation of hazard risks, such as avalanches and snow creep. Changes in forest structure can modify the snow regime and protective effect.

Methods

We quantified snow interception across forest developmental stages and canopy closure in a spruce-dominated landscape on the Pokljuka Plateau, using multi-temporal UAV-borne ALS before and after a November 2022 snowfall. Snow depth was derived from snow-on/off terrain models and compared with Rudno Polje station data. Stand structure (canopy height, canopy closure, and field-calibrated developmental stage classes), as well as a canopy projection-based interception index were derived from ALS data.

For more information visit:
Snowfall interception

Interception is **lowest** in **very young** and **very old** stands and **highest** at **intermediate** stages with continuous crowns. **Increasing canopy closure amplifies interception**, producing a non-linear peak at intermediate heights.

The findings highlight the importance of forest structure for snow cover dynamics and provide directly applicable insights for regeneration planning and protective forest management in mountain environments.

Interreg Co-funded by the European Union Alpine Space
MOSAIC
INRAE
BF UNIVERZA V LJUBLJANI Biotehniška fakulteta

Case study

Italy

EXPLOITING FACILITATION MECHANISMS BY DEADWOOD IN ACTIVE RESTORATION

Nicolò Anselmetto, Matteo Garbarino, Raffaella Marzano
University of Turin (UNITO)

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, on shaded sides, under shrub cover) significantly **improves establishment success.**

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

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

For more information visit: MOSAIC WebGIS Atlas

Post-fire regeneration

Deadwood facilitates post-fire forest regeneration by:

- **Protecting seedlings 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 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 efforts where natural regeneration is insufficient.

Methods

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

Interreg Alpine Space
Co-funded by the European Union
MOSAIC
UNIVERSITÀ DI TORINO

PARTIAL SALVAGE LOGGING AND DEADWOOD MANIPULATION

Tommaso Baggio, Davide Marangon, Paul Richter, Emanuele Lingua
University of Padua (UNIPD)

Risk mitigation

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

Partial salvage logging is a post-disturbance technique consisting of harvesting deadwood to a limited extent. 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 enhance the protective effect in disturbed areas.

Planning deadwood-based protection

- **Identify** the type of natural hazard to be mitigated.
- **Analyze** the amount of deadwood to be retained on site and/or the types of deadwood structures to be implemented.
- **Evaluate** the duration of the mitigation effect of deadwood and/or deadwood manipulation structures.

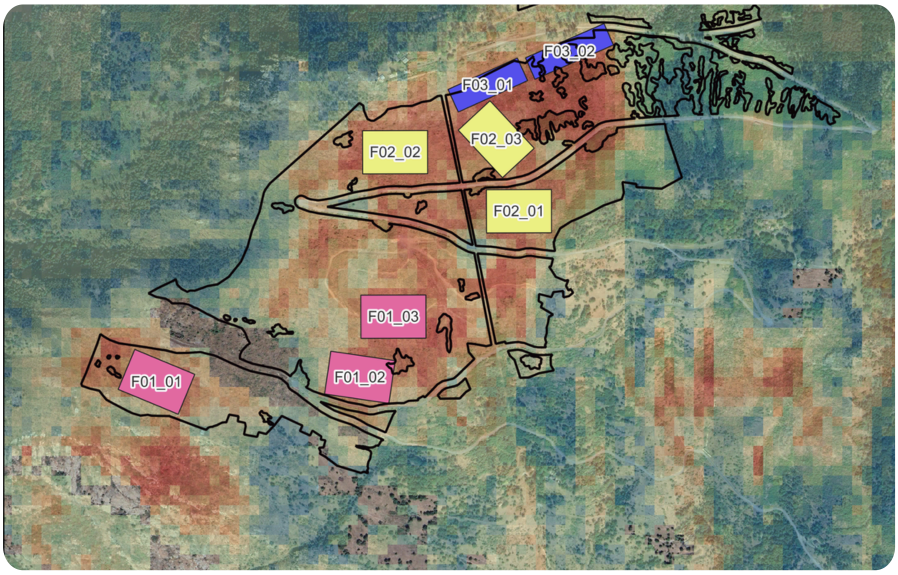
Salvage logging can create harsher microclimate and reduce regeneration potential.

Its use should be limited to safety-critical zones, such as roads and other infrastructure.

For more information visit:
MOSAIC WebGIS Atlas

Best practice example

Italy



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

Nicolò Anselmetto, Matteo Garbarino, Raffaella Marzano
University of Turin (UNITO)

Targeted planting

Natural regeneration is preferable after disturbances, but can be limited by salvage logging, harsh climate, or a 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 sites in the Western Alps, using disturbance, distance to seed trees, topography, and species suitability as predictors.
- Models produced **presence probability maps**, which identified areas with low regeneration and defined priority seeding polygons.
- Planting in groups near deadwood or under shrub cover is recommended.

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

Microsite manipulations (deadwood or shrub shelter) enhance seedling establishment.

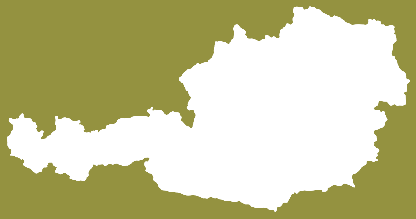
Combining spatial modeling with applied nucleation provides a robust framework for restoration, optimizing resources and resilience.

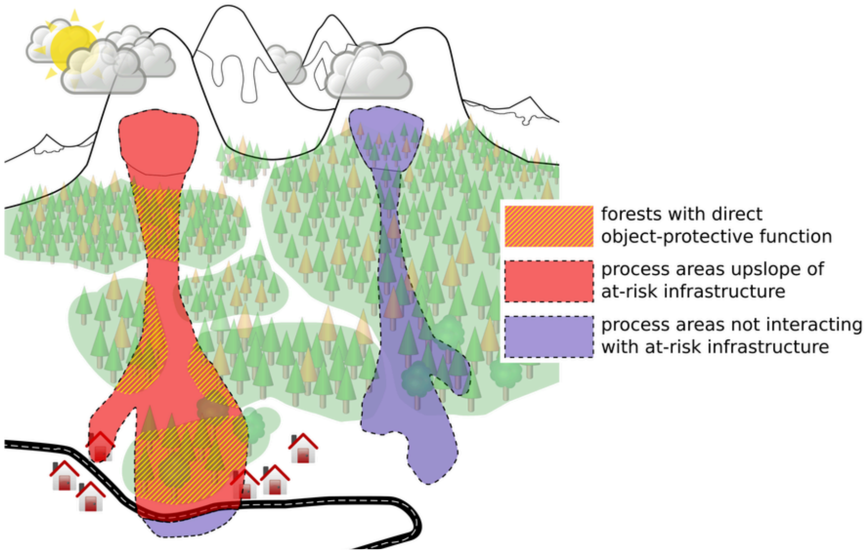
Interreg Alpine Space
Co-funded by the European Union
MOSAIC
UNIVERSITÀ DI TORINO

For more information visit: MOSAIC WebGIS Atlas

Best practice example

Austria





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

Frank Perzl, Andreas Huber, Laura Saxer, Michaela Teich
Austrian Research Centre for Forests (BFW)

Identifying object-protective forests

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

Management support

Protective forest maps derived from modeling are valuable instruments for protective forest and natural hazard management. They support the planning, prioritization, and monitoring of silvicultural and other protective measures, and provide a basis for further analyses, such as assessing the socioeconomic value of protective forests.

Protective forest areas upslope of assets must be identified through **spatial modeling**.

Large-scale applications require tools, that can operate with limited data, ensure robust hazard-tracking functionality, and provide sufficient computational capacity.

The empirical-topographical mass movement model **com4FlowPy** was developed to support Austrian forest function planning and has been released as an open-source tool. It includes a back-tracking functionality to identify process areas upslope of at-risk infrastructure, where protective forests or afforestation measures can mitigate snow avalanches, rockfall, and shallow landslides.

Interreg Co-funded by the European Union
Alpine Space
MOSAIC

BFW AUSTRIAN RESEARCH CENTRE FOR FORESTS

More information at: Open Natural Hazard Modeling

Best practice example

Austria

LYING DEADWOOD FOR SNOW AVALANCHE PROTECTION

Leon Bührle and Michaela Teich
Austrian Research Centre for Forests (BFW)

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

Based on windthrow case studies, the proposed tool uses **high-resolution drone surveys to provide spatially explicit assessments of protective effects, thereby guiding management priorities and identifying needs for additional silvicultural and protection measures.**

Modeling avalanche release likelihood

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

Factors shaping protective effectiveness

The protective effect varies with deadwood structure, regeneration, and slope steepness. However, deadwood generally provides sufficient surface roughness to prevent frequent avalanche release. These factors should be considered when deciding on deadwood retention for avalanche protection.

Protective effect assessment

Drone data enable an objective assessment of the protective effect of lying deadwood against snow avalanche release. Under frequent snow conditions, lying deadwood generally provides strong protection. Management must carefully balance these protective benefits with safety considerations and bark beetle control.

Interreg Co-funded by the European Union
Alpine Space
MOSAIC

BFW AUSTRIAN RESEARCH CENTRE FOR FORESTS

More information at: Open Natural Hazard Modeling

Case study
Austria

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

Andrew Giunta and Michaela Teich
Austrian Research Centre for Forests (BFW)

This case study investigates how elevation, thinning, and species composition influence tree development over 60 years following the afforestation of an alpine pasture in the Sellrain Valley, Tyrol, Austria.

Height, DBH, and crown growth declined with increasing elevation, especially during the first 40 years.

Thinning enhanced individual tree growth, but reduced stand density and basal area. **Regular thinning improved stand stability and kept mortality below 1%, compared to 50% in unthinned plots, emphasizing its importance for sustaining protective forests.**

For more information visit:
Projekt BERGAUF

Comparison methods

Tree parameters were measured at ages 25, 30, 38, and 54 in six study plots. 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.

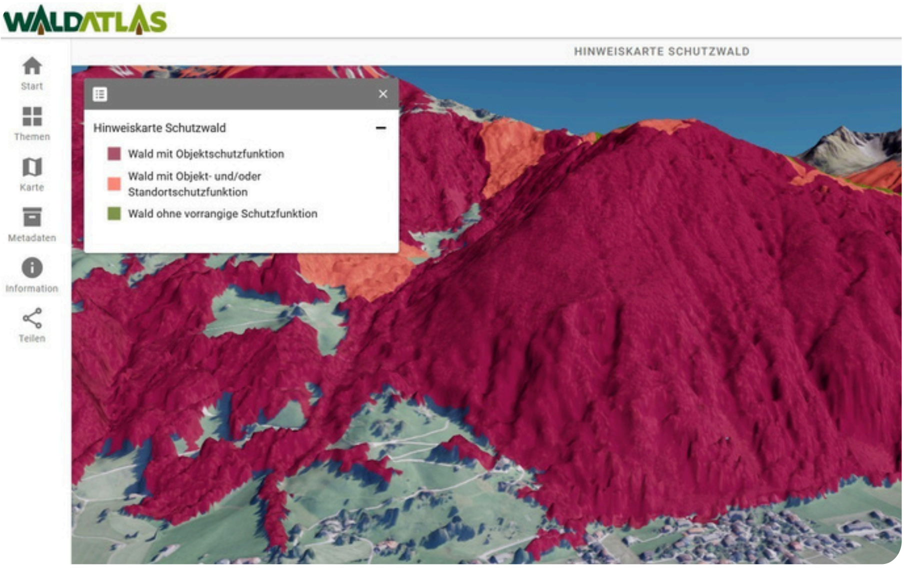
Key lessons

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

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.

Best 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 Austrian Research Centre for Forests (BFW)

What is WALDATLAS?

WALDATLAS is Austria's **interactive digital forest spatial information system** and a central nationwide platform, that provides 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 forests with protective functions, and is provided by the Federal Ministry of Agriculture and Forestry, Climate and Environmental Protection, Regions and Water Management (BMLUK).

Interactive mapping tool

WALDATLAS is a web-based map service providing an interactive map interface with more than 80 regularly updated, quality-checked thematic maps supported by reliable base layers.

WALDATLAS is the first Austrian map service to offer a 3D view with thematic overlays of aerial images, enabling a visualization of terrain and forest conditions, as well as their relationships to, for example, the location of hazard zones or 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 derived from models or remote-sensing and validated by regional forestry and natural-hazard authorities. The geodata support analyses of protective forests, natural hazards, and biodiversity, along with BMLUK reports and publications.

AUSTRIAN RESEARCH CENTRE FOR FORESTS

For more information visit: WALDATLAS

Best practice example

Switzerland

NaiS: SWISS GUIDELINES FOR OPTIMISED MANAGEMENT IN PROTECTIVE 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 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 a widely used, practical, and scientifically grounded tool for forest management and natural hazard mitigation.

NaiS guidelines also served as a basis for the French national guidelines, as well as the guidlines in the Valle d'Aosta in Italy.

Protective forest assessment

Protective forest stands and natural hazards (e.g. avalanches, rockfall, shallow landslides) are identified.
Forest condition is assessed using NaiS criteria and reference profiles, with a focus on structure, species composition, stability, regeneration, and site conditions.
Comparison with NaiS requirements defines management needs, while a regional controlling system monitors the maintenance or improvement of protective functions. Success monitoring is conducted on NaiS indicator plots – areas managed according to NaiS guidelines, which are subsequently monitored.

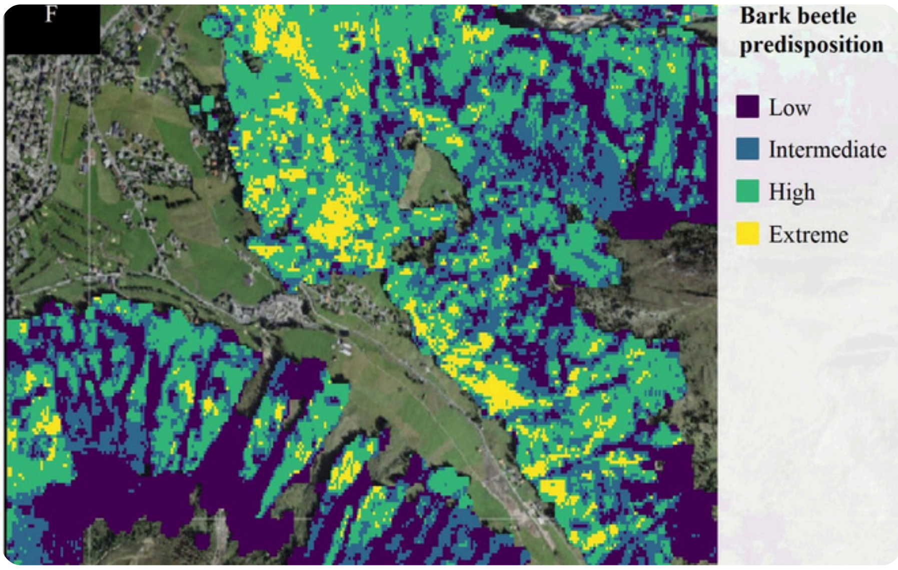
From research to practice

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 integrating climate change impacts.

For more information visit: NaiS

Best practice example

Switzerland



PRIORITIZING OF REQUIRED MANAGEMENT INTERVENTIONS IN SPRUCE-DOMINATED MOUNTAIN FORESTS

Peter Bebi , Leon Bührle, Kevin Helzel
Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

Background

Given limited resources, forest management interventions must be transparently prioritized. This prioritization should integrate multiple criteria, including predisposition assessment to windthrow and bark beetle outbreaks, the importance of ecosystem services, resilience, and recovery potential, as well as technical and economic feasibility of potential management interventions.

Mapping disturbance risks

Predisposition maps for windthrow, bark beetles, and snow breakage are created using high-resolution forest structure parameters and site factors which are weighted by an expert-based model. 140 field assessments by foresters and the comparison to actual bark beetle outbreaks showed a high reliability of the predisposition maps.

More informaiton at: MountEx project

- **Forest structure and site data** are derived from nationwide high-resolution ALS data to create predisposition maps.
- **Risk reduction value** of the protective forest is calculated using detailed natural hazard simulations (snow avalanches, rockfall) and the risk approach EconoMe.
- **Potential loss of protective function** under severe disturbance scenarios (bark beetle outbreaks and windthrow) was assessed using predisposition maps and changes in calculated risk.

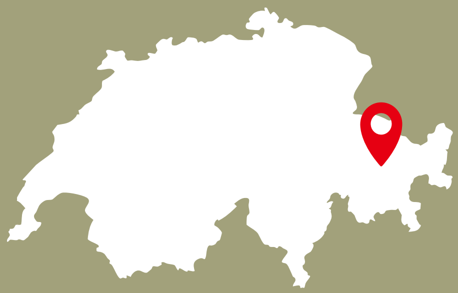
Future application

The framework is currently being expanded in several Swiss cantons and is transferable to other mountain regions. It supports operational planning, evaluation of management interventions, protective forest modeling, disturbance scenario analysis, and its future integration into an interactive decision-support system.

WSL
Interreg Alpine Space MOSAIC
Co-funded by the European Union

Research site

Switzerland



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.

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 temperature, micro topography, and snow cover, while later development is increasingly shaped by exposure to wind, mechanical damages, and competition between trees.

The influence of environmental factors changed substantially during juvenile tree growth and differed among species, emphasizing the **importance of long-term observations** for understanding forest management near treeline.

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.

Interreg Co-funded by the European Union
Alpine Space
MOSAIC
WSL

For more information visit:
Stillberg research

Case study
Switzerland

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

Christine Moos
Bern University of Applied Sciences (HAFL)

Structural support

This case study, which was conducted in the Swiss Western Alps, focused on the economic efficiency of combining protective forests with structural measures against rockfall. The study demonstrated that hybrid solutions are efficient alternatives and the protection goals cannot be achieved with the forest alone.

Assessment methods

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

Conclusion

Increasing drought under climate change can critically shift forest composition and structure, potentially leading to a temporary reduction in the forest's protective effect. Diversity is essential for climate adaptation and resilience to extreme events.

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

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

For more information visit:
Efficient hybrid protection

Bern University of Applied Sciences
School of Agricultural, Forest and Food Sciences HAFL
Interreg Alpine Space
Co-funded by the European Union
MOSAIC

Case study

Switzerland

INFLUENCE OF GAP SIZE ON REGENERATION OF LIGHT-DEMANDING SPECIES

Markus Graf[1], Jean-Jacques Thormann[1], Christine Moos[1], Petia Nikolova[2]
1 Bern University of Applied Sciences (HAFL), 2 Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)

Gap size effect on regeneration

This case study in the Bernese Alps examined the influence of gap size on regeneration density of light-demanding species. The study emphasizes 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 Bernese Alps, all located in the montane elevation zone. Stem density and height of regeneration were analyzed with respect to gap width, forest cover, competing vegetation, browsing intensity, and topographical characteristics. The method follows approaches used in other case studies in Switzerland.

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 cover degree of competing vegetation or browsing intensity, must be considered for effective interventions in protective forests.

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 increasing gap size.**

A plausible explanation for this finding is the high light availability promoting competing vegetation and hindering natural regeneration on majority of the sites.

Additionally, browsing damages were frequent, but **did not significantly limit regeneration.**

For more information visit:
Influence of gap size on regeneration

5. References

CHAPTER 1. INTRODUCTION

Bebi P., Seidl R., Motta R., Fuhr M., Firm D., Krumm F., Conedera M., Ginzler C., Wohlgemuth T., Kulakowski D. 2017. Changes of forest cover and disturbance regimes in the mountain forests of the Alps. Forest Ecology and Management 388: 43-56. https://doi.org/10.1016/j.foreco.2016.10.028

Brang P., Schönenberger W., Ott E., Gardner B. 2001. Forests as protection from natural hazards. In: The forests handbook: Applying forest science for sustainable management. Evans, J. (ed.). Oxford, Blackwell Science, 2: 53-81. https://doi.org/10.1002/9780470757079.ch3

Rey, F., Dupire, S., Berger, F. 2024. Forest-based solutions for reconciling natural hazard reduction with biodiversity benefits. Nature-Based Solutions 5. https://doi.org/10.1016/j.nbsj.2024.100114

Moos C., Stritih A., Teich M., Bottero A. 2023. Mountain protective forests under threat? An in-depth review of global change impacts on their protective effect against natural hazards. Frontiers in Forests and Global Change, 6. https://doi.org/10.3389/ffgc.2023.1223934

Teich M., Accastello C., Perzl F., Berger F. 2022. Protective forests for ecosystem-based disaster risk reduction (Eco-DRR) in the alpine space. In: Protective forests as ecosystem-based solution for disaster risk reduction (Eco-DRR). IntechOpen. http://dx.doi.org/10.5772/intechopen.99505

CHAPTER 2. SILVICULTURAL MEASURES IN PROTECTIVE FORESTS

Diaci J. 2012. Varovalni gozdovi: razvojne zakonitosti, ocena tveganja, usklajevanje gojenja gozdov in tehnologij izkoriščanja. Project report. University of Ljubljana, Biotechnical Faculty, 26 pp.

Kajdiž P., Diaci J., Rebernik J. 2015. Modelling facilitates silvicultural decision-making for improving the mitigating effect of beech (Fagus sylvatica L.) dominated Alpine forest against rockfall. Forests, 6, 6: 2178–2198. https://doi.org/10.3390/f6062178

Motta, R., Haudemand, J. C. 2000. Protective forests and silvicultural stability. Mountain Research and Development, 20, 2: 180–187. https://doi.org/10.1659/0276-4741(2000)020[0180:PFASS]2.0.CO;2

Ringenbach A., Bebi P., Bartelt P., Rigling A., Christen M., Bühler Y., Stoffel A., and Caviezel A. 2023. Shape still matters: rockfall interactions with trees and deadwood in a mountain forest uncover a new facet of rock shape dependency. Earth Surface Dynamics, 11: 779–801. https://doi.org/10.5194/esurf-11-779-2023

Spadoni G. L., Moris J. V., Kirschner J., de Miguel S., Oliveras Menor I., Passamani C., Terzuolo P., Gottero F., Le Moguédec G., Ascoli D., Motta R. 2026. Active and passive forest management: Effects on ecosystem services across protected and unprotected areas in a Southern European regional context. Forest Ecology and Management, 602. https://doi.org/10.1016/j.foreco.2025.123387

Teich M., Accastello C., Perzl F., Berger F. 2022. Protective forests for ecosystem-based disaster risk reduction (Eco-DRR) in the alpine space. In: Protective forests as ecosystem-based solution for disaster risk reduction (Eco-DRR). IntechOpen. http://dx.doi.org/10.5772/intechopen.99505

Vilhar U. 2024. Načrtovalske in gozdnogojitvene smernice ter urepi za gospodarjenje z gozdovi v hudourniških območjih za krepitev varovalne in zaščitne funkcije gozdov. Findings report. Slovenian Forestry Institute, 31 pp.

CHAPTER 2. SILVICULTURAL MEASURES IN PROTECTIVE FORESTS

IMPROVING FOREST STAND STABILITY

Bošeľa M., Konôpka B., Šebeň V., Vladovič J., Tobin B. 2014. Modelling height-to-diameter ratio as an opportunity to increase Norway spruce stand stability in the Western Carpathians. Central European Forestry Journal, 60, 2: 71–80. https://doi.org/10.2478/forj-2014-0007

Ma Y., Zhang X., Jiang R., Jiang M., Ju J. 2025. Effects of stand structural characteristics, diversity, and stability on carbon storage across different densities in natural forests: A case study in the Xiaolong Mountains, China. Forests, 16, 1: 71. https://doi.org/10.3390/f16010071

O'Hara K. L. 2006. Multiaged forest stands for protection forests: concepts and applications. Forest Snow and Landscape Research, 80, 1: 45–55.

Sharma R. P., Vacek Z., Vacek S., Kučera M. 2019. A nonlinear mixed-effects height-to-diameter ratio model for several tree species based on Czech National Forest Inventory data. Forests, 10, 1: 70. https://doi.org/10.3390/f10010070

Wonn H. T., O'Hara K. L. 2001. Height-diameter ratios and stability relationships for four northern Rocky Mountain tree species. Western Journal of Applied Forestry, 16, 2: 87–94. https://doi.org/10.1093/wjaf/16.2.87

Zhu J., Song L. 2021. A review of ecological mechanisms for management practices of protective forests. Journal of Forestry Research, 32, 2: 435–448. https://doi.org/10.1007/s11676-020-01233-4

IMPROVING TREE SPECIES COMPOSITION UNDER CLIMATE CHANGE

Austrian Federal Forests (Österreichische Bundesforste), 2021. Protection Forest – Seven Good Reasons. Brochure. Vienna: Österreichische Bundesforste AG.

Bauerhansl C., Berger F., Dorren L., Duc P., Ginzler C., Kleemayr K., Koch V., Koukal T., Mattiuzzi M., Perzl F., Prskawetz M. 2010. Development of harmonized indicators and estimation procedures for forests with protective functions against natural hazards in the alpine space (PROALP). Institute for Environment and Sustainability, Office for Official Publications of the European Communities. https://doi.org/10.2788/51473

Motta, R., Haudemand, J. C. 2000. Protective forests and silvicultural stability. Mountain Research and Development, 20, 2: 180–187. https://doi.org/10.1659/0276-4741(2000)020[0180:PFASS]2.0.CO;2

Oettel J., Lapin K. 2021. Linking forest management and biodiversity indicators to strengthen sustainable forest management in Europe. Ecological Indicators, 122: 107275. https://doi.org/10.1016/j.ecolind.2020.107275

CHAPTER 2. SILVICULTURAL MEASURES IN PROTECTIVE FORESTS

OPTIMISING SPATIAL DISTRIBUTION OF TREES

Spiekermann R. I., McColl S., Fuller, I., Dymond J., Burkitt L., Smith H. G. 2021. Quantifying the influence of individual trees on slope stability at landscape scale. Journal of Environmental Management, 286, 112194. https://doi.org/10.1016/j.jenvman.2021.112194

Scheidl C., Heiser M., Vospernik S., Lauss E., Perzl F., Kofler A., Kleemayr K., Bettella F., Lingua E., Garbarino M., Skudnik M., Trappmann D. Berger, F. 2020. Assessing the protective role of alpine forests against rockfall at regional scale. European Journal of Forest Research, 139, 6: 969-980. https://doi.org/10.1007/s10342-020-01299-z

Schönenberger W., Noack A., Thee P. 2005. Effect of timber removal from windthrow slopes on the risk of snow avalanches and rockfall. Forest ecology and management, 213, 1-3: 197-208. https://doi.org/10.1016/j.foreco.2005.03.062

FOREST GAPS MANAGEMENT

Dietze L., Lefèvre C., Davi J. P., Longdoz B., Le Dantec V., Grégoire, J. C. 2020. Windstorm-Induced Canopy Openings Accelerate Temperate Forest Adaptation to Global Warming. Global Ecology and Biogeography, 29, 11: 2067-2077. https://doi.org/10.1111/geb.13177

Marangon D., Betetto C., Wohlgemuth T., Cadez L., Alberti G., Tomelleri E., Lingua E. 2024. Impact of Salvage Logging on Short-Term Natural Regeneration in Montane Forests of the Alps after Large Windthrow Events. Forest Ecology and Management 567, 122085. https://doi.org/10.1016/j.foreco.2024.122085

Schmid U., Bigler C., Frehner M., Bugmann H. 2021. Abiotic and biotic determinants of height growth of Picea abies regeneration in small forest gaps in the Swiss Alps. Forest Ecology and Management, 490, 119076. https://doi.org/10.1016/j.foreco.2021.119076

Wohlgemuth T., Schwitter R., Bebi P., Sutter F., Brang P. 2017. Post-windthrow management in protection forests of the Swiss Alps. European Journal of Forest Research, 136, 5-6: 1029-1040. https://doi.org/10.1007/s10342-017-1031-x

NATURAL REGENERATION MANAGEMENT

Čater M., Železnik P. (ur.). 2012. Forests and forestry in Slovenia. Vol. 115. Ljubljana, Slovenian Forestry Institute, Silva Slovenica Publishing Centre. 120 pp.

Diaci J. 2021. Gozdna ekologija in nega: univerzitetni učbenik. Ljubljana, Biotehniška fakulteta, Oddelek za gozdarstvo in obnovljive gozdne vire, Univerza v Ljubljani, 434 pp.

CHAPTER 2. SILVICULTURAL MEASURES IN PROTECTIVE FORESTS

ACTIVE RESTORATION THROUGH PLANTING AND SEEDING

Chakraborty D., Ciceu A., Ballian D., Benito Garzón M., Bolte A., Božić G.,.., Schueler S. 2024. Assisted tree migration can preserve the European forest carbon sink under climate change. Nature Climate Change, 14, 8: 845-852. https://doi.org/10.1038/s41558-024-02080-5

INTEGRATED DEADWOOD MANAGEMENT

Marcolin E., Marzano R., Vitali A., Garbarino M., Lingua E. 2019. Post-fire management impact on natural forest regeneration through altered microsite conditions. Forests, 10, 11: 1014. https://doi.org/10.3390/f10111014

Marzano R., Garbarino M., Marcolin E., Pividori M., Lingua E. 2013. Deadwood anisotropic facilitation on seedling establishment after a stand-replacing wildfire in Aosta Valley (NW Italy). Ecological Engineering, 51: 117-122. https://doi.org/10.1016/j.ecoleng.2012.12.030

Wohlgemuth T., Schwitter R., Bebi P., Sutter F., Brang P. 2017. Post-windthrow management in protection forests of the Swiss Alps. European Journal of Forest Research, 136, 5: 1029-1040. https://doi.org/10.1007/s10342-017-1031-x

CHAPTER 3. BIOTECHNICAL MEASURES IN PROTECTIVE FORESTS

Dorren L. 2022. Introduction. In: Using timber to counter natural hazards: Erosion, Landslide, Torrent, Avalanche. G. Ratsch (Ed.). Lignum technical briefing papers on timber use, 68 pp.

Dorren L., Berger F. 2012. Integrating forests in the analysis and management of rockfall risks: Experiences from research and practice in the Alps. In: Landslides and engineered slopes: Protecting society through improved understanding. Eberhardt E., Froese C., Turner A. K., Leroueil S. (eds). Taylor & Francis Group, pp 117-127.

Cej T. 2025. Sodobni tehnični ukrepi za obvladovanje erozije. Rejda, okoljske rešitve, d.o.o. (unpublished).

Kunej S. 2025. Izvedba sečnje v zaščitnih gozdovih. Zavod za gozdove Slovenije (unpublished).

Proierozijski ukrepi v gozdovih. Opis praktičnih primerov ukrepov, ki povečujejo erozijsko odpornost. 2025. Zavod za gozdove Slovenije (unpublished).

Saražin J., Vilhar U., Papež J., Dovečar M. 2025. Katalog tehničnih rešitev, ki prispevajo k povečanju erozijske odpornosti v gozdovih. Gozdarski inštitut Slovenije (unpublished).

CHAPTER 4. BEST PRACTICE EXAMPLES, RESEARCH AND CASE STUDIES FROM ALPINE SPACE COUNTRIES

MARTELOSCOPE AS AN EDUCATIONAL TOOL FOR PROTECTIVE FOREST MANAGEMENT

European Forest Institute (EFI) 2020. iPLUS documentation. http://iplus.efi.int/documentation.html (10. sep. 2025)

MAKING RESEARCH WORK: INTEGRATION FORUMS FOR EFFECTIVE NATURAL HAZARD MANAGEMENT

Böcher M., Krott M. 2016. Science makes the world go round: Successful scientific knowledge transfer for the environment. Cham, Springer. https://doi.org/10.1007/978-3-319-34079-1

Kirchner M., Krott M. 2022. Making science-based natural hazard risk management work within power networks: From co-production models of knowledge transfer to the Research-Integration-Utilisation (RIU) model. International Journal of Disaster Risk Reduction, 76: 103362. https://doi.org/10.1016/j.ijdrr.2022.103362

SLOVENIA

POST WINDTHROW NATURAL REGENERATION CAN PROVIDE MORE RESILIENT FORESTS
Research in Jelovica plateau, Slovenia

Bončina Ž., Klopčič M., Poljanec A. 2018. Natural regeneration after a windstorm in pure secondary Norway spruce forests in the Alps: Is European beech coming home? In: Proceedings of the 11th International Beech Symposium, Book of Abstracts, Slovenia Forest Service & University of Ljubljana. https://alfredodifilippo.com/wp-content/uploads/2019/03/iufrobeech2018_proof.pdf (23. jan. 2026).

Poljanec A., Trifković V., Bončina A., Sever K., Nève Repe A., Klopčič M. 2025. Dynamics of natural regeneration following the 2006 windstorm in the mountain forests of the Slovenian Alps. In: Proceedings of the IMC – International Mountain Conference. Innsbruck, Austria.

ENSURING PROTECTIVE FOREST FUNCTION USING NATURE-BASED SOLUTIONS IN SOTESKA

Kunej S. 2025. Field visit of a protective forest in Soteska. Bohinjska Bistrica, Slovenian Forest Service (personal communication, may 2025).

INNOVATIVE FOREST REGENERATION IN FIRE-AFFECTED AREAS
Research in Karst region, Slovenia

22 Med. 2024. After the forest fires: How to make the new trees more resistant? https://www.22-med.com/en/after-the-forest-fires-how-to-make-the-new-trees-more-resistant/ (10.sep.2025)

CHAPTER 4. BEST PRACTICE EXAMPLES, RESEARCH AND CASE STUDIES FROM ALPINE SPACE COUNTRIES

Advexure 2025. Reforestation by air: How seed-planting drones are restoring forests. Los Angeles, Advexure. https://advexure.com/blogs/news/reforestation-by-air-how-seed-planting-drones-are-restoring-forests (10.sep.2025)

Projekt O2. 2025. Presentation of O2 project and seeding seed bombs with drones. Mosaic project meeting, Bohinjska Bistrica. (unpublished)

Rantaša B. 2024. Poskus povečanja uspešnosti obnove gozdov na Goriškem Krasu po požaru z uporabo zadrževalnikov vode in mikorize. (unpublished)

SNOW INTERCEPTION IN MONTANE SPRUCE FORESTS

Mencin N. 2023. Intercepcija snežnih padavin glede na razvojno fazo smrekovih sestojev na Pokljuki. Oddelek za gozdarstvo in obnovljive gozdne vire, Biotehniska fakulteta, Univerza v Ljubljani, 46 pp.

ITALY

EXPLOITING FACILITATION MECHANISMS BY DEADWOOD IN ACTIVE RESTORATION

Lingua E., Marques G., Marchi N., Garbarino M., Marangon D., Taccaliti F., Marzano R. 2023. Post-fire restoration and deadwood management: Microsite dynamics and their impact on natural regeneration. Forests, 14, 9: 1820. https://doi.org/10.3390/f14091820

PARTIAL SALVAGE LOGGING AND DEADWOOD MANIPULATION

Leverkus A.B., Rey Benayas J.M., Castro J., Boucher D., Brewer S., Collins B.M., Gustafsson L. 2018. Salvage logging effects on regulating and supporting ecosystem services—A systematic map. Canadian Journal of Forest Research, 48, 9: 983-1000. https://doi.org/10.1139/cjfr-2018-0114

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

Mantero G., Anselmetto N., Morresi D., Meloni F., Bolzon P., Lingua E., Marzano R. 2024. Modeling post-fire regeneration patterns under different restoration scenarios to improve forest recovery in degraded ecosystems. Forest Ecology and Management, 551: 121520. https://doi.org/10.1016/j.foreco.2023.121520

CHAPTER 4. BEST PRACTICE EXAMPLES, RESEARCH AND CASE STUDIES FROM ALPINE SPACE COUNTRIES

AUSTRIA

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

D'Amboise C.J.L., Teich M., Hormes A., Steger S., Berger F. 2021. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Protective forests as ecosystem-based solution for disaster risk reduction (Eco-DRR). IntechOpen. https://doi.org/10.5772/intechopen.99510

Huber A., Perzl F., Fromm R., Fischer J.-Th., Klebinder K., Sotier B. 2013. Development of a simple raster-based model for gravitational mass movement processes applied to the regional assessment of forest stands with direct protective functionality. In: International Snow Science Workshop 2013 Grenoble – Chamonix Mont-Blanc, Proceedings, pp. 697-703.

Perzl F., Bono A., Garbarino M., Motta R. 2021. Protective effects of forests against natural hazards. In: Protective forests as ecosystem-based solution for disaster risk reduction (Eco-DRR). IntechOpen. https://doi.org/10.5772/intechopen.99506

Perzl F., Starsich A. 2024. The first Austrian indication map of protective forests showing their object-protective function cartographically. In: INTERPRAEVENT 2024 Conference Proceedings, pp. 711-715. International Research Society INTERPRAEVENT, Klagenfurt, Austria.

Sinabell F., Reschenhofer P., Freudenschuß A. 2024. Towards an assessment of the economic benefits of protective forest. In: INTERPRAEVENT 2024 Conference Proceedings, pp. 220-223. International Research Society INTERPRAEVENT, Klagenfurt, Austria.

LYING DEADWOOD FOR SNOW AVALANCHE PROTECTION

Baggio T., Brožová N., Bast A., Bebi P., D'Agostino V. 2022. Novel indices for snow avalanche protection assessment and monitoring of wind-disturbed forests. Ecological Engineering, 181: 106677. https://doi.org/10.1016/j.ecoleng.2022.106677

BAFU 2008. Sturmschaden-Handbuch: Vollzugshilfe für die Bewältigung von Sturmschadenereignissen von nationaler Bedeutung im Wald. Bundesamt für Umwelt (BAFU).

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

Kronfuss H. 1997. Das Klima einer Hochlagenaufforstung in der subalpinen Höhenstufe – Haggen im Sellraintal bei St. Sigmund, Tirol (Periode 1975-1994). FBVA-Berichte.

Kronfuss H., Havranek W.M. 1999. Effects of elevation and wind on the growth of Pinus cembra L. in a subalpine afforestation. Phyton, 39, 4: 99–106.

Markart G. 2000. Zum Wasserhaushalt von Hochlagenaufforstung – am Beispiel der Aufforstung von Haggen bei St. Sigmund im Sellrain. Bericht der Forstlichen Bundesversuchsanstalt Wien, Nr. 117.

Giunta, A., Teich, M., Ledermann, T., Meier, R., Suntinger, N., Markart, G., Schindlbacher, A. 2026. Long-term forest development following afforestation of an alpine pasture and repeated thinning in the Central European Alps. New Forests 57: 41. https://doi.org/10.1007/s11056-026-10172-7

WALDATLAS: Austria's hub for geodata on protective forests and natural hazards

Perzl F., Starsich A. 2024. The first Austrian indication map of protective forests showing their object-protective function cartographically. In: INTERPRAEVENT 2024 Conference Proceedings, pp. 711-715. International Research Society INTERPRAEVENT, Klagenfurt, Austria.

Starsich A., Oswald V. 2024. WALDATLAS – The geodata platform for the forest, natural hazards and biodiversity. In INTERPRAEVENT 2024 Conference Proceedings, pp. 228–231. International Research Society INTERPRAEVENT, Klagenfurt, Austria.

SWITZERLAND

NaiS: SWISS GUIDELINES FOR OPTIMISED MANAGEMENT IN PROTECTIVE FORESTS

Frehner M., Stoffel M., Stoffel L. 2005. Nachhaltigkeit und Erfolgskontrolle im Schutzwald NaiS: Vollzugshilfe für Pflegemaßnahmen in Wäldern mit Schutzfunktion. Bundesamt für Umwelt (BAFU).

PRIORITIZING OF REQUIRED MANAGEMENT INTERVENTIONS IN SPRUCE-DOMINATED MOUNTAIN FORESTS

Bast A., Hobi M.L., Ginzler C., Piermattei L., Fischer C., Nikolova P.S., Graf F. 2025. An approach to detect and map forest canopy layers in Swiss mountain forests using nationwide airborne laser scanning data. International Journal of Applied Earth Observation and Geoinformation, 145: 104986. https://doi.org/10.1016/j.jag.2025.104986

Bebi P., Schweier J. (Eds.) 2023. Aus Störungen und Extremereignissen im Wald lernen. In: WSL Berichte, 144. Forum für Wissen 2023. https://doi.org/10.55419/wsl:35217

Bont L., Blattert C., Schweier J., Bührle L., Helzel K., Bebi P., Nikolova P.S. 2023. Mountain spruce forests as hotspots for extremes: Optimal allocation of the limited resources of a forest enterprise. In: WSL Berichte, 144. Forum für Wissen 2023. Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL.

CHAPTER 4. BEST PRACTICE EXAMPLES, RESEARCH AND CASE STUDIES FROM ALPINE SPACE COUNTRIES

Bont L.G., Blattert C., Rath L., Schweier J. 2024. Automatic detection of forest management units to optimally coordinate planning and operations in forest enterprises. Journal of Environmental Management, 372: 123276. https://doi.org/10.1016/j.jenvman.2024.123276

Bottero A., Bührle L., Banzer T., Helzel K., Bast A., Hobi M., Bebi P. 2023. Störungsanfälligkeitskarten zur Priorisierung der Waldbewirtschaftung. Bündnerwald, 76, 4: 46-49.

Hobi M., Brandes T., Bebi P., Helzel K., Bottero A., Bührle L., Schweier J. 2025. Bewirtschaftung von fichtendominierten Gebirgswäldern im Kontext extremer Störungen. In: WSL Berichte, 164. Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL, Birmensdorf.

LESSONS FROM AFFORESTATIONS NEAR TREELINE

Lechler L., Rixen C., Bebi P., Bavay M., Marty M., Barbeito I., Frei E.R. 2024. Five decades of ecological and meteorological data enhance the mechanistic understanding of global change impacts on the treeline ecotone in the European Alps. Agricultural and Forest Meteorology, 355: 110126. https://doi.org/10.1016/j.agrformet.2024.110126

Piazza N., Bottero A., Gaume J., Vacchiano G., Marcer M., Bebi P. 2025. Growing trees decrease the frequency of avalanche release in an alpine afforestation in the Swiss Alps. Cold Regions Science and Technology, 239: 104612. https://doi.org/10.1016/j.coldregions.2025.104612

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

Moos C., Bebi P., Bottero A. Submitted. Combining modeling and expert-based evaluation to assess climate change impacts on the protective service of forests. Manuscript submitted for publication.

Moos C., Bebi P., Bottero A. 2024. Kombination von Schutzwald und technischen Schutzbauten: Zunehmende Bedeutung von "hybriden Ansätzen" im Klimawandel. FAN Agenda, 2/2024. https://doi.org/10.24451/dspace/11508

INFLUENCE OF GAP SIZE ON REGENERATION OF LIGHT-DEMANDING SPECIES

Graf M. 2024. Analyse der Verjüngung in Schutzwaldschlägen im Berner Oberland. MSc Thesis, Bern University of Applied Sciences.

MOSAIC

Managing prOtective foreSt fAcIng clImate Change compound events

https://www.alpine-space.eu/project/mosaic/
https://alpineresilience.org/