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Alpine Space

MOSAIC

Educational concept for training of adaptive and integrated measures in forests with protective functions

MOSAIC – Managing protective forest facing climate change compound events

WP3 – FORCE: Forest labs for raising awareness on resilience of protective forest coping with climate change

Activity 3.1: Establishment of network of forest living labs equipped with virtual tool and solutions for knowledge transfer

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Deliverable 3.1: A common educational concept for training of adaptive and integrated measures in forests with protective functions

Activity 3.1 leader: Slovenian Forest Service

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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 3.1 Establishment of forest living labs network equipped with virtual tool and solutions for knowledge transfer

Forest living labs (FLLs) are established in hotspot areas identified in WP1 in each project partner country and will serve as a research, training and awareness raising tool. A virtual tool (app) and a common educational concept for training of adaptive and integrated measures in forests with protective functions, which are potentially at risk due to climate change compound events, will be produced.

Deliverable 3.1: Report on forest living labs network equipped with virtual tool and solutions for knowledge transfer

The report presents the process used for establishing a FLLs network, virtual tool and educational concept for training, including feedback from various users. The goal of the educational concept is to transfer knowledge through a virtual tool that supports a better understanding and application of silvicultural measures in protective forests.

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1. INTRODUCTION

Forest Living Labs (FLLs) network, equipped with virtual tools and solutions for knowledge transfer, represents one of the key outputs of the MOSAIC project. Forest Living Labs are established in each project partner country within hotspot areas for natural hazards and gravitational processes identified in WP1. These Living Labs serve as platforms for research, training, awareness raising, and addressing challenges related to climate change.

The FLLs support the development, testing, and demonstration of adaptive forest management approaches aimed at increasing forest resilience to climate-related risks. A core component of each FLL is the establishment of marteloscope plots designed for training in tree selection (for cutting or retention) and silvicultural decision-making. These plots are used in combination with a training tool, the I+ Trainer application for tablet computers, which allows users to perform virtual thinning on the marteloscope plot.

Within the MOSAIC project, the I+ Trainer application was upgraded with an additional protective forest module. This module is specifically designed to support training in silvicultural measures in protective forests, where the primary management objective is to enhance stand stability and maintain or improve the forest's protective effect against natural hazards.

This educational concept provides a framework for conducting training sessions on marteloscope plots using the I+ Trainer application. It supports trainers in organizing structured, field-based learning activities focused on thinning and other adaptive silvicultural measures in protective forests under changing climate conditions. The concept promotes practical learning, interactive decision-making, and the integration of digital tools into forestry education and professional training.

2. ADAPTIVE SILVICULTURAL TRAINING IN PROTECTIVE FORESTS

2.1. FOREST LIVING LABS

Within the MOSAIC project, the Living Lab (LL) approach is applied to enable experimental learning, active stakeholder engagement, and the iterative adaptation of methods and measures. In the MOSAIC project, Forest Living Labs are established in forests of the Alpine region that are threatened by climate change impacts and gravitational processes. They are established to address key forest management challenges in complex landscapes, particularly in protective forests on steep slopes that often protect infrastructure, livelihoods, and the forest stands themselves. Their focus is on testing adaptive management approaches that enhance forest resilience to disturbances such as gravitational processes, pests, windthrow, and other climate-related risks. A central aim is to strengthen the protective effect of forests against natural hazards, support biodiversity, and enable collaboration between researchers and practitioners through real-world experiments and long-term monitoring.

2.2. MARTELOSCOPES AND I+TRAINER APPLIACTION

A marteloscope is a forest training plot used for experiential learning in forest management and decision-making (Figure 1). It serves as a platform for knowledge transfer, where participants can practice and compare different silvicultural decisions in a realistic forest environment. Marteloscopes are primarily used to support training in tree selection, thinning, and the evaluation of silvicultural measures, helping users understand the ecological and economic consequences of their silvicultural decisions.

Marteloscopes are used together with the I+ Trainer application, developed by the European Forest Institute (EFI), which enables the interactive simulation of management scenarios (Figure 2). Through this tool, users can test different strategies, such as selective thinning, habitat tree retention, or wood production-oriented management, and immediately see the results of their silvicultural decisions in the application. This approach supports discussion, reflection, and collaborative learning among forestry professionals and other users.

More information about marteloscopes plots and I+ Trainer is available here: http://iplus.efi.int/

Instructions for using the I+Trainer application are available in the following tutorial document: http://iplus.efi.int/uploads/20240104_I%2BTrainer_Tutorial_en.pdf

Figure 1: Marteloscope plot with tree number identification

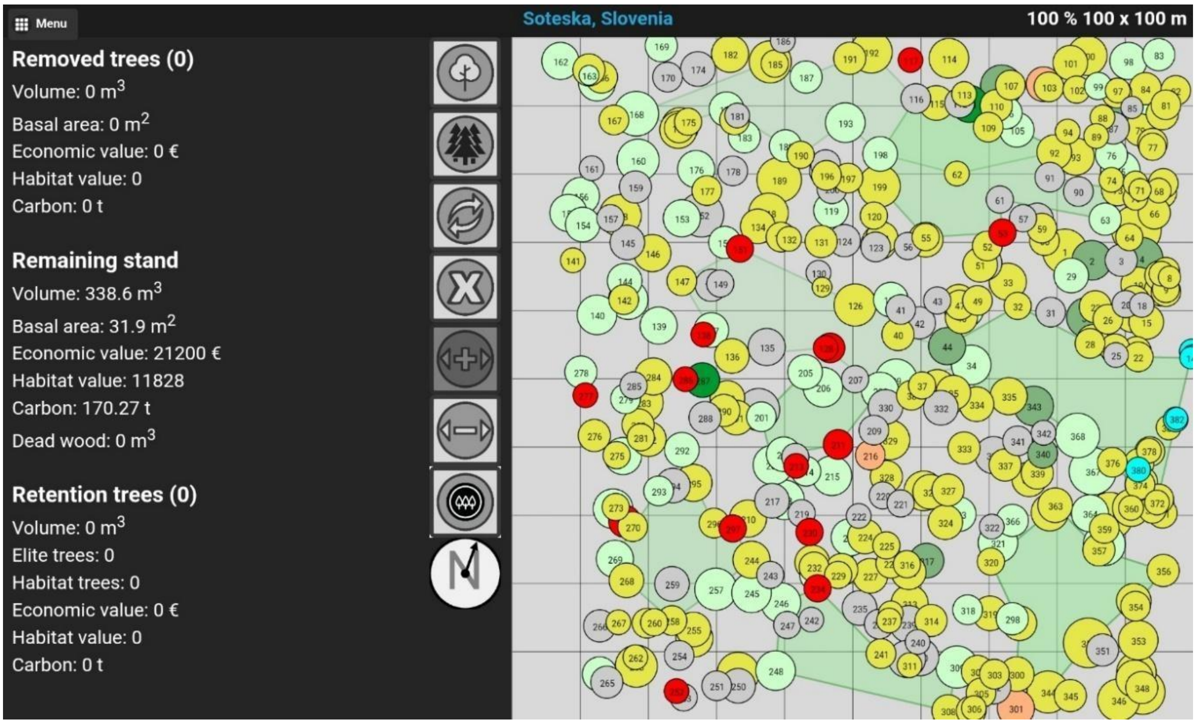


Figure 2: Marteloscope plot interface in the I+trainer application

2.3. MARTELOSCOPE ESTABLISHMENT

A marteloscope is typically established as a permanent, measured forest plot (usually 1 ha in size) designed for training in tree selection, silvicultural decision-making, and the evaluation of management options. According to the marteloscope setup guidelines (http://iplus.efi.int/uploads/Marteloscope_Guidelines_Setup.pdf), the key steps include:

- **Full tree inventory** – A suitable stand is selected and clearly defined, followed by a full tree inventory and mapping, including the diameter, height, species, and spatial position of all trees. Each tree is then numbered and georeferenced, allowing precise identification in the field and in digital tools.
- **Ecological and economic value** – In addition, relevant ecological attributes are recorded, such as habitat trees, deadwood, crown condition, and structural diversity. The economic value is based on timber quality, tree dimensions, and market value, representing the potential economic return from harvesting.
- **Database integration** – These data are integrated into a database linked to a digital decision-support system, which allows users to simulate interventions (e.g. thinning or selective cutting) and immediately see the economic and ecological consequences in the I+ Trainer application.
- **Representative plot** – A key element is that the plot must be representative of real forest management conditions so that training outcomes are transferable to practice. The system is designed so that users can make decisions in the field using tablets and instantly compare alternative management scenarios.

To establish a marteloscope in a protective forest, several additional aspects should be considered:

- The site is usually located **on steep or difficult terrain** but must **remain safe** for group training. It should clearly represent a forest with a protective function (e.g. a forest protecting a road, infrastructure, or a settlement) (Figure 3).
- The plot should include or reflect **natural hazards or risk factors**, such as rockfall, erosion, snow avalanches, windthrow, or other relevant hazards, so that participants can assess stability-related silvicultural decisions. At the same time, the area must be carefully selected to ensure **safe access** and controlled training conditions.
- Finally, the site should allow **easy access and logistics and ideally have a nearby place** (e.g. a shelter, classroom, or restaurant) for group discussion, reflection, and analysis after field exercises.

Figure 3: Marteloscope Soteska (Slovenia) established in a protective forest

2.4. THE UPGRADE OF I+TRAINER APPLICATION WITH MOSAIC PROTECTIVE MODULE

Within the I+Trainer, a protective forest module is being developed under the MOSAIC project to support decision-making in forests, where the protective function is more important than other functions e.g. timber production. The module allows users to evaluate how silvicultural interventions influence forest stability and protective effectiveness, showing whether management actions strengthen or weaken the protective effect against rock fall, snow avalanches and shallow landslides.

The module development was based on a multi-step, participatory approach involving literature review, expert assessment, stakeholder input, and project partner evaluation. First, key protective indicators were identified from scientific literature. These indicators were then evaluated by practitioners and experts according to their importance for (1) stand stability and (2) prevention of slope processes such as rockfall, snow avalanches, and landslides. The results were ranked and used as the basis for selecting the most relevant indicators for the module.

The final set of protective indicators and indexes (e.g. stand stability, regeneration, root system development, gap structure, stand composition etc.) is integrated into the simulation environment. In the same way as economic and habitat values are calculated in I+Trainer, the protective module quantifies changes in protective effectiveness under different management scenarios.

The main goal of the module is to improve and strengthen knowledge of protective forest management and, in doing so, enhance the protective effect of forests. The module enables users to test management options in advance, better understand cause-and-effect relationships, and support more informed and risk-sensitive silvicultural decision-making in protective forest conditions.

To enhance the assessment of the forest's protective effect within the I+Trainer application, several new features and indicators were incorporated:

- **Protective effect module** – a new "Protective effect" module was added to the application, incorporating key protective features and indicators (Figure 4).
- **Protective features table** – by selecting the "Protective effect" module, users can access the "Protective features" table. This table presents the protective indicators identified as the most relevant during the evaluation process, together with their definitions and descriptions. It also explains the interpretation of low and high indicator values and their significance within I+Trainer training scenarios (Figure 5).
- **Reasons for removal and retention of trees** – additional selection buttons were introduced to support the assessment of the forest's protective value. These allow users to identify trees that should be retained due to their protective effect, as well as trees that may be removed for forest stand stability improvement (Figure 6).
- **Additional protective indicators presented in maps** – few tree parameters were added as protective indicators to support stability assessment of trees. For each tree, the application now displays indicators such as the height-to-diameter (h/d) ratio, crown asymmetry, and stem inclination, providing valuable information on tree stability and its contribution to protective forest effect (Figure 6). This indicators and stem injuries are also presented in a map, where bigger circles represent trees with higher values (Figure 8).

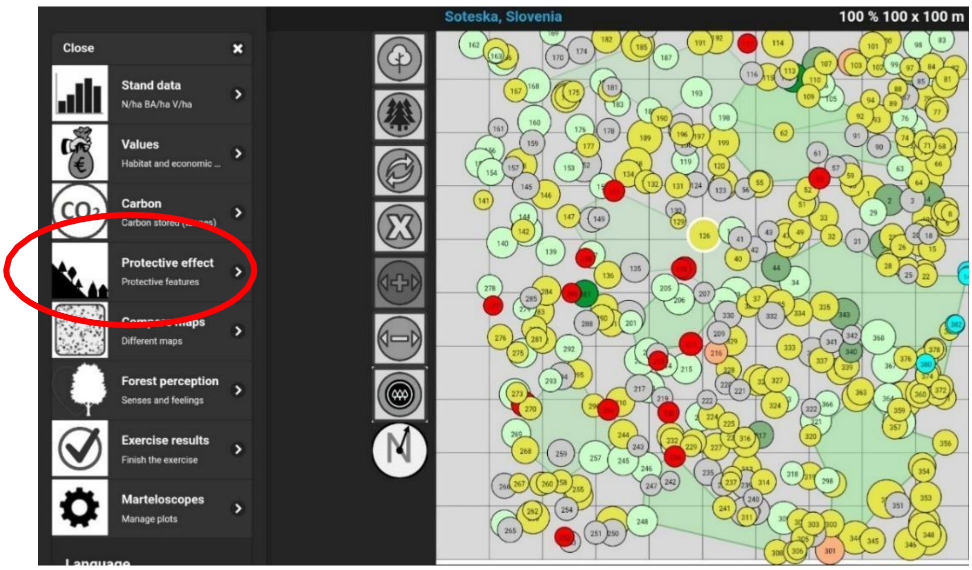


Figure 4: Protective effect module upgrade in the I+trainer application

Protective features

Parameter	Value	Definition	Description
1 Stem density (N per ha)	383	Number of trees per hectare	High values indicate more obstacles and a higher protective effect. Low values indicate more gaps and a lower protective effect. Ideal for rockfall protection in mixed forests: > 300 trees/ha.
2 Stand basal area (m²/ha)	31.86	Total cross-sectional area of all trees per hectare	Optimal stand basal area for rockfall protection is ≥ 25 m²/ha.
3 DBH (cm)	30.62	Average diameter at breast height	The optimal average DBH in a protective forest generally ranges between 30 and 50 cm, aiming to balance structural stability, stand density, and continuous cover.
4 Slope (°)	30	The steepness or incline of a surface	Higher slope increases the hazard of slope-related processes and reduces the protective effect of forests.
5 Slope lenght (m)	250	The length of the forested slope	A longer slope provides a greater distance for rockfall to decelerate and stop, thereby improving its protective effect.
6 Average rock diameter (m)	1	Average diameter of rocks deposited in the forest stand	Larger rocks have more energy, making them harder to stop and reducing the protective effect of forests.
7 Rock density (kg/m3)	2800	The mass of a rock per unit volume	Higher density means heavier rocks, resulting in greater impact energy.
8 Initial fall height (m)	30	Height of the rockfall source area	A higher rockfall drop results in greater energy and increasing hazard risk.
9 Deciduous tree species (%)	67.36	Percentage of deciduous tree species	Deciduous trees intercept more energy from falling rocks than conifers. In avalanche protection, evergreen trees, such as conifers, provide the highest protective effect.
10 Forest cover (%)	73.11	Percentage of ground area that is covered by the vertical projection of tree crowns.	Higher crown cover increases the protective effect against shallow landslides.
[illegible]		Crown asymmetry is the degree to which a	Asymmetrical crowns can increase tree instability. Values in %

Figure 5: Presentation of protective features in the I+trainer application

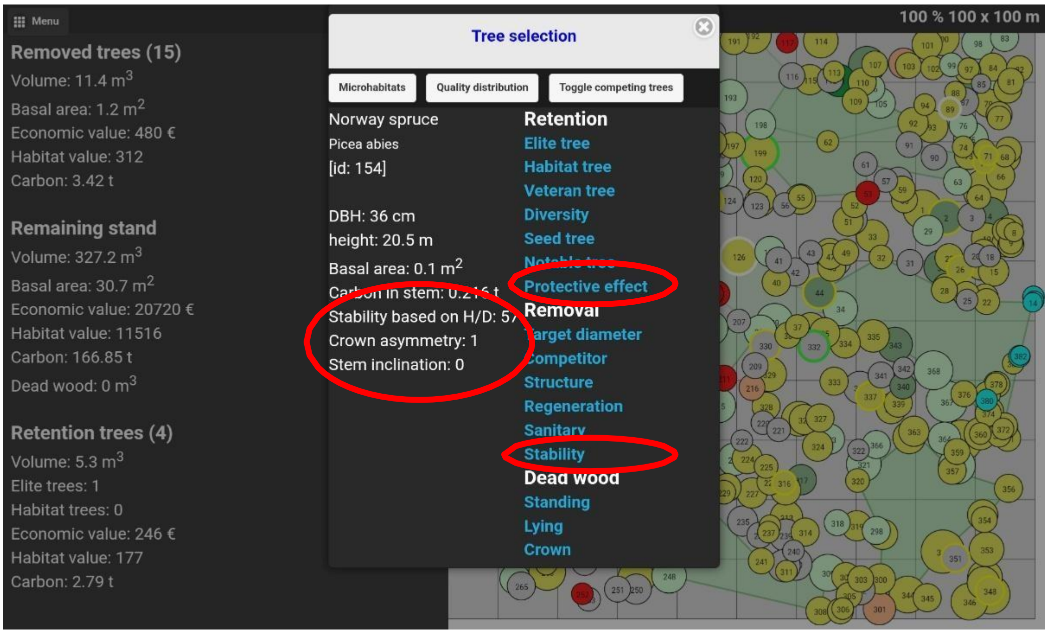


Figure 6: Protective indicators and tree selection options for protective forest management

3. PROTECTIVE INDICATORS

Protective indicators are quantitative and qualitative variables used to evaluate the ability of a forest stand to reduce the impacts of gravitational processes, such as rockfall, snow avalanches, and shallow landslides. They describe both stand structure (e.g. density, stability, and species composition of trees) and external hazard conditions (e.g. slope and rock size). Together, they form the basis for calculating **protective indexes** in the I+ Trainer simulation system. These indicators allow users to understand how forest structure influences the protective effect and how different silvicultural decisions (e.g. thinning or tree retention) modify the forest's risk reduction capacity.

3.1. Overview and description of protective indicators

Stand structure indicators

The indicators listed below can be used to assess the protective effect of a forest and are described in more detail in Table 1. It is important to keep in mind that these indicators are often interrelated and should not be considered individually. For example, stand density alone does not provide sufficient information; it should be evaluated together with tree distribution and stand structure.

- **HD ratio (slenderness)** - key indicator used to assess the stability of trees. H/D = tree height (m) / diameter at breast height (m). Trees with a high HD ratio are generally less stable and more prone to breaking or uprooting, especially in exposed areas. Ideal HD ration is less than 80 (for conifers); example: for a tree with height of 25 m, the optimal DBH would be 31 cm or more.

- **Stem density (N/ha)** - Number of trees per hectare. Higher density increases obstacles for falling rocks and improves protective effect (for mixed forest optimal is > 300 trees/ha).

- **Spatial distribution of trees (map)** - An even spatial distribution of trees within a stand can reduce the movement of rocks and snow and contribute to slope stability, thereby reducing the risk of shallow landslides. A well-distributed stand also promotes a more interconnected root system, which increases soil cohesion and enhances the stabilizing effect of the forest on the slope.

- **Stand structure (tree diameter distribution)** - The most suitable stands are structurally diverse, with multiple canopy layers, a wide range of tree diameters, and even distribution and presence of understory. On suitable sites, an uneven-aged stand structure with appropriate tree species provides the highest level of stability. Such a structure increases stand resilience and minimizes the formation of large canopy gaps, which may increase the risk of slope instability and gravitational processes. The presence of understory vegetation and shrub species is also important, as it helps prevent erosion, reduces the velocity of falling material (e.g. snow or rocks), and contributes to soil moisture retention.

- **Stand basal area (m²/ha)** - An appropriate stand basal area (neither too high nor too low) ensures sufficient stem density and root development to provide mechanical protection and maintain soil stability. In protective forests on steep slopes exposed to rockfall, the optimal basal area is generally ≥ 25 m²/ha, depending on slope gradient, rock size, and stand characteristics. For example, in alpine and subalpine beech forests in the Soteska area (Bohinjska Bistrica, Slovenia), the optimal basal area ranges between 50 and 68 m²/ha. It can be calculated with this tool: https://www.ecorisq.org/rockfor-net-en

- **Average DBH (cm)** – The optimal average DBH in a protective forest generally ranges between 30 and 50 cm, aiming to balance structural stability, stand density, and continuous cover.

- **(Regeneration) gaps (the size and orientation of the gaps)** - Excessively large gaps oriented downhill (i.e. in the direction of the slope) can act as channels that accelerate slope processes and therefore pose a significant risk. In contrast, smaller gaps oriented transversely to the slope present a lower risk, facilitate natural regeneration, and do not significantly reduce the forest's protective effect. Properly planned regeneration areas ensure continuous protection against slope processes while maintaining stand stability. Regeneration of protective forests is essential because it promotes structural diversity and supports the natural development of the forest. Small regeneration gaps positioned transversely to the slope, together with the gradual expansion of regeneration areas, are therefore recommended.

- **Crown asymmetry (% of trees with crown asymmetry)** - Crown symmetry influences tree stability, particularly in forests on steep slopes. An evenly distributed crown reduces the risk of stem breakage or tree overturning under wind and snow loads. In contrast, asymmetrical crowns create uneven mechanical stress, increasing the likelihood of instability, particularly on sloping terrain.

- **Stem inclination (% of trees with stem inclination)** - can affect tree stability, particularly in protective forests on steep slopes. Trees with significantly inclined stems have their center of gravity shifted away from the vertical axis, resulting in an uneven distribution of forces within the root system. In stable protective stands, trees should therefore have upright stems with minimal inclination (< 15°), as this improves their mechanical stability and increases their resistance to natural disturbances.

- **Root system (% of trees with deep root system)** - The root system plays a key role in the stability of individual trees and forest stands. A strong, well-developed root system reduces the risk of uprooting during wind and snow events and on unstable terrain. Tree roots bind the soil, increasing its cohesion and thereby reducing the risk of erosion and shallow landslides. Tree species differ in their rooting patterns: some develop deep root systems (e.g. larch), while others have shallow root systems (e.g. spruce). However, this does not mean that only deep-rooted species should be promoted. Species selection should always consider site conditions and the natural tree species composition of the forest.

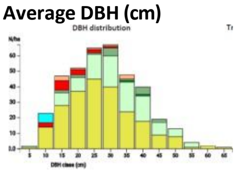
- **Stem injuries (% of trees with mechanical damage)** - Mechanical damage (e.g. injuries like bark loss, stem damage), often caused by rock impacts indicate where and how often rockfall occurs. By observing the injuries, we can assess: 1) effectiveness of the stand in stopping the falling rocks; 2) vulnerability of individual trees or forest areas, and 3) potential direction of rock movement. Information about stem injuries can help in planning thinning and harvesting operations, in order to maintain the forest's protective effect.

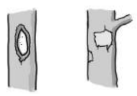
- **Deciduous tree species (% of broadleaves) -** Deciduous tree species are generally more effective at dissipating rockfall energy than coniferous species because they typically have denser wood. In contrast, evergreen conifers are generally more suitable for protection against snow avalanches. Ideally, forest stands exposed to snow avalanche risk should contain around 70% evergreen conifers. However, this does not mean that only broadleaved or coniferous species should be promoted. Species selection should always consider site conditions and the natural tree species composition of the forest.

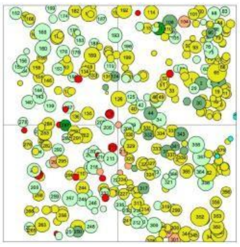
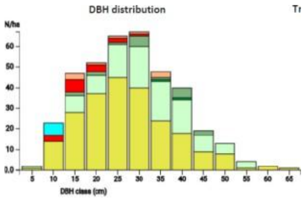
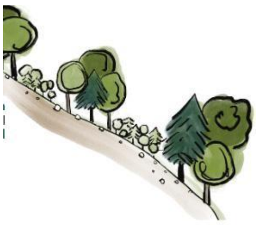
- **Forest cover (% of crown cover)** - Crown cover within a stand influences several protective functions. It protects the soil against erosion, enhances snow retention and thereby reduces snow avalanche risk, decreases wind speed within the stand, and contributes to protection against windthrow. For protection against snow avalanches, the optimal crown cover is above 70%, while values below 30% are considered critical.

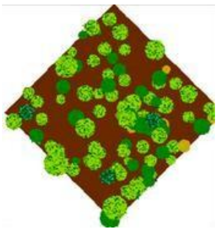
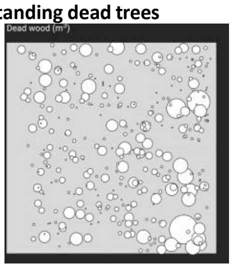
- **Deadwood (m^3/ha, spatial distribution)** - Fallen logs and branches increase the roughness of the terrain and can retain, redirect, and slow the movement of rocks, snow, and soil material, thereby reducing their downslope movement. In relatively dense and stable stands, deadwood often acts as a natural barrier against snow avalanches and erosion. In addition, decomposing wood retains moisture, supports biodiversity, and promotes natural regeneration. However, excessive amounts of deadwood on the ground may also pose a risk. By adding additional biomass to the forest floor and locally affecting slope stability, they may contribute to erosion or shallow landslides under certain site conditions.

Table 1: Protective indicators for forest stand description

Protective indicators	Field measurements	Calculation	I+trainer	Interpretation	Thresholds	References
H/D ratio (slenderness) 	Tree height (m) and DBH measured at 1.3 m (cm) for all trees ≥ 15 cm DBH.	H/D = tree height (m) / DBH (m); calculated per tree.	Displayed as HD for each tree and on a spatial map defined by circle size, based on the value of H/D ratio.	Indicates tree mechanical stability. High values above 100 mean tall, thin trees with higher risk of windthrow or breakage. Low values below 80 indicate more stable trees with stronger stems.	**< 80 stable, 80–100 unstable, > 100 very unstable.** **for conifers* .	Burschel and Huss (1997), Abetz (1987), Pach et al. (2021), Moreno-Fernández et al. (2025), Frehner et al. (2005), Skrzyszewski and Pach (2021).
Stem density (N/ha) 	All trees within the marteloscope plot are counted and spatially mapped.	Number of trees per hectare (N/ha).	Displayed as a total value and a spatial map of trees.	Higher density increases interception capacity and root reinforcement of soil.	Optimal protective range depends on slope, but generally **>300 trees/ha** improves rockfall protection.	Meyer-Grass and Schneebeli (1992), Bauerhansl et al. (2010).
Stand basal area (m²/ha) 	DBH (diameter at breast height) measured for each tree.	Sum of tree basal areas (π·DBH²/4) per hectare.	Displayed as a numeric value and a spatial distribution map.	Higher values indicate stronger mechanical protection and maintain soil stability.	Protective function generally increases above **~25 m²/ha.**	Bauerhansl et al. (2010).
Average DBH (cm) 	DBH measured for all trees at 1.3 m height.	Arithmetic mean of all measured DBH values.	Displayed as a stand average numeric value and class distribution.	Balanced diameter structure indicates stable protective stands.	DBH of **30–50 cm** for optimal balance of stand stability and density.	Brang et al. (2006), Diaci et al. (2015).
Crown asymmetry (%) 	Visual assessment of crown balance in two classes: 0 = no asymmetry, 1 = slight to significant asymmetry.	Percentage of trees with asymmetric crowns.	Proportion of trees, class for each tree and a spatial map highlighting trees with asymmetric crowns (class 1).	High asymmetry increases susceptibility to windthrow and snow damage.	**Optimal forest stands** are characterized by predominantly **symmetrical to slightly asymmetrical crowns.**	Young and Perkocha (1994), Kon et al. (2021), Mauer et al. (2007)

Stem inclination (%) 	Visual assessment of stem inclination in two classes: 0= straight or less than 15 inclined°, 1 = more than 15° inclined.	Proportion of trees inclined more than 15°.	Proportion of trees, class for each tree and a spatial map highlighting trees with inclined stems (class 1).	High values reduce structural stability.	**Stem inclination < 15 °** of the vertical axis = **optimal tree form.**	Mauer et al. (2007), Labelle et al. (2016), Prendes et al. (2022).
Root system (%) 	Assigned by species-based classification (deep / medium / shallow).	Percentage of trees with deep root systems.	Proportion of tree species with deep root system.	Deep root system increases slope stability and soil cohesion.	**Shallow root system:** Norway spruce, sycamore maple, rowan, manna ash, hazel, aspen, and grey alder. **Moderate root system:** silver fir, black pine, silver birch, common whitebeam, hornbeam, and Wych elm. **Deep root system:** European beech, European larch, oak species, European ash, and Scots pine.	Pietig et al. (2026), Brus (2005), Benning (n.d.).
Stem injuries (%) 	Recording microhabitats of bark loss and injuries for each tree.	Percentage of trees with visible damage.	Spatial "impact map" of mechanical injuries. Circle size on map is defined by number/ intensity of stem injuries per tree.	Indicates past hazard pathways and intensity.	It works only in stands with no management and active rockfall. We are assuming that these injuries come from rockfall.	Kraus et al. (2016), Žabota et al. (2020).
Deciduous tree species (%) 	Species inventory of all trees.	Proportion of deciduous trees.	Proportion of deciduous trees.	Broadleaves generally dissipate energy more effectively than conifers. Conifers are generally more suitable for protection against snow avalanches.	Mixed stands with a **balanced proportion** of deciduous and coniferous species, depending on site conditions and hazard type.	Motta and Haudemand (2000).
Forest cover (%)	Crown projection estimation or remote sensing/grid method.	Percentage of ground area covered by crowns.	Percentage of ground area covered by crowns.	Higher crown cover reduces snow avalanche risk, erosion and surface runoff.	**Continuous forest cover** is necessary, as canopy continuity is essential for	Brang et al. (2006).

					maintaining protective effect of forests against natural hazards.	
Tree distribution 	Spatial coordinates of all trees mapped on the marteloscope plot (x–y position).	Spatial location of trees in the map.	Displayed as spatial map of all trees.	Describes how trees are spatially arranged within the marteloscope. A more regular and well-distributed pattern improves the interception of rockfall and snow, promotes a more interconnected root system, and enhances slope stability. In contrast, clustered or highly uneven tree distributions, with bigger gaps may create weak zones and increase the concentration of rockfall or snow movement.	**An even spatial distribution of trees is desirable for protection**, **while strong clustering or large spatial gaps result in reduced protective effect.**	Meyer-Grass and Schneebeli (1992).
Stand structure 	DBH (cm), species.	Diameter distribution per species.	Displayed as a diameter class histogram.	Describes overall structural complexity of the forest. Uneven-aged stands increase mechanical stability and improve resistance to rockfall, wind, and snow.	**Optimal stands are structurally diverse, with multiple canopy layers, a wide range of tree diameters, and even distribution and presence of understory.**	Brand et al. (2006), Diaci et al. (2015).
(Regeneration) gaps 	Spatial mapping of canopy openings (tree coordinates and polygon delineation), density (seedlings/ha), height classes, and species composition of regeneration	Gap size (m²), shape, and orientation on slope direction.	Map of regeneration gaps (polygons) with species composition and height classes.	Gaps influence acceleration pathways of rockfall and snow. Small, irregular gaps improve regeneration, while large downslope-oriented gaps increase hazard risk.	**Large gaps in the slope direction**, exceeding **1–2 times the height** of the surrounding trees, should be avoided. Smaller regeneration gaps maintain long-term stability and structural continuity.	Meyer-Grass and Schneebeli (1992), Bauerhansl et al. (2010). Oettel and Lapin (2021).

Crown closure 	Crown projection per tree (field estimate or GIS-based canopy model)	Percentage of crown-covered area.	Spatial canopy cover map (continuous surface or grid-based estimation). **Not present in the I+trainer (yet).*	High crown closure reduces soil erosion, intercepts precipitation, and slows down rock/snow movement.	**Optimal stand crown cover** is **above 70%,** while values below 30% are considered critical.	Protection forest – Seven good reasons (2021).
Standing dead trees 	Inventory of dead trees, DBH, height and location.	Number of standing dead trees per hectare.	Map of dead trees.	Indicates disturbance history and habitat value.	Moderate amounts of deadwood contribute to biodiversity, whereas excessive amounts may reduce stand stability. In areas where infrastructure is at risk, standing dead trees should be removed.	Wohlgemuth et al. (2017).
Lying deadwood biomass 	Measurement of logs (length, diameter, decay class).	Volume (m^3/ha) and spatial distribution of deadwood.	Map display of deadwood pieces and volume classes. **Not present in the I+trainer (yet).*	Moderate amounts of deadwood contribute to biodiversity. Deadwood can slow rock and snow movements and reduce erosion, but excessive accumulation may increase instability on steep slopes.	At least **2 logs per 10 m.** **Log diameter** should be **greater than the expected rock diameter** in gaps larger **than 20 m.** In areas where infrastructure is at risk, standing dead trees should be removed.	Wohlgemuth et al. (2017).

3.2. Spatial presentation of protective features

By using the maps available in the I+ Trainer application, users can visualize the spatial distribution of trees together with their attributes and interpret the protective effect across the stand. Each tree is displayed according to its location and recorded attributes, allowing users to visually assess:

- Gaps with or without regeneration in a forest stand (Figure 7),
- Stable and unstable trees based on the HD ratio, stem inclination, and crown asymmetry (Figure 8),
- Rockfall paths, which indicate areas with a higher protective capacity based on the presence of stem injuries (Figure 8).

This spatial visualization helps users understand how stand heterogeneity and different attributes influences the forest's protective effect, providing both a visual and quantitative interpretation of stand conditions.

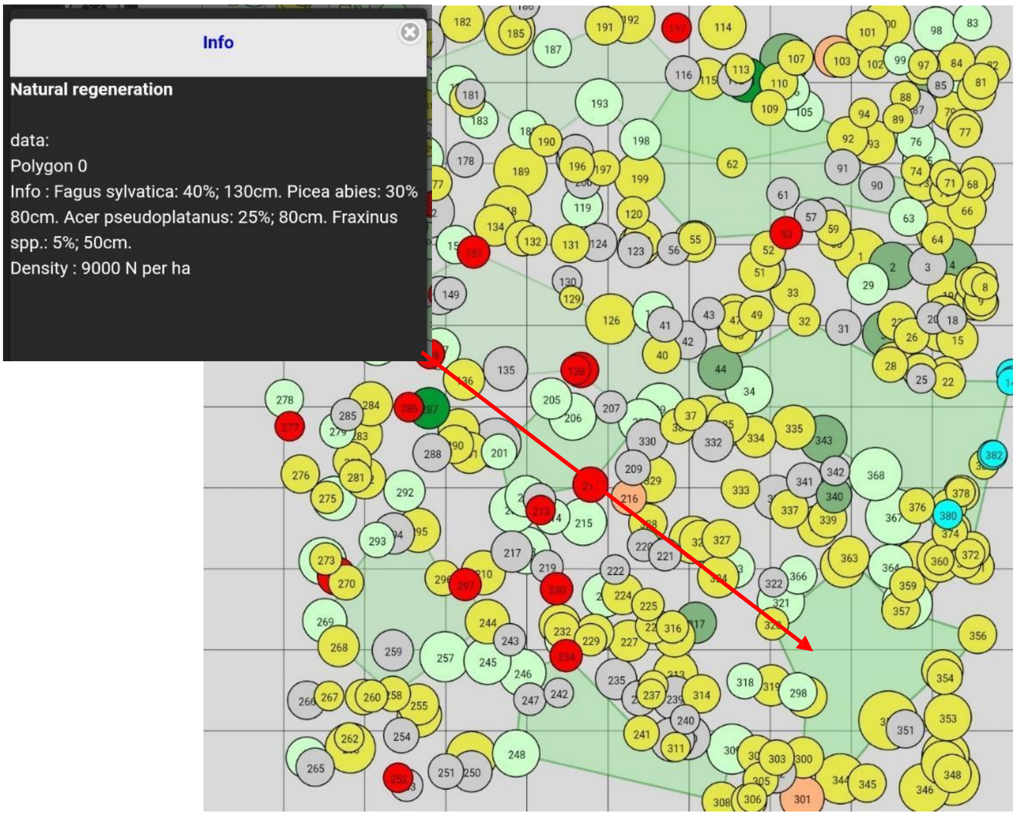


Figure 7: Natural regeneration gaps are displayed as polygons (green color) and include detailed information on tree species composition (percentage of seedlings), average seedling height by species, and seedling density per hectare. Gaps without regeneration are displayed as grey spaces between trees.

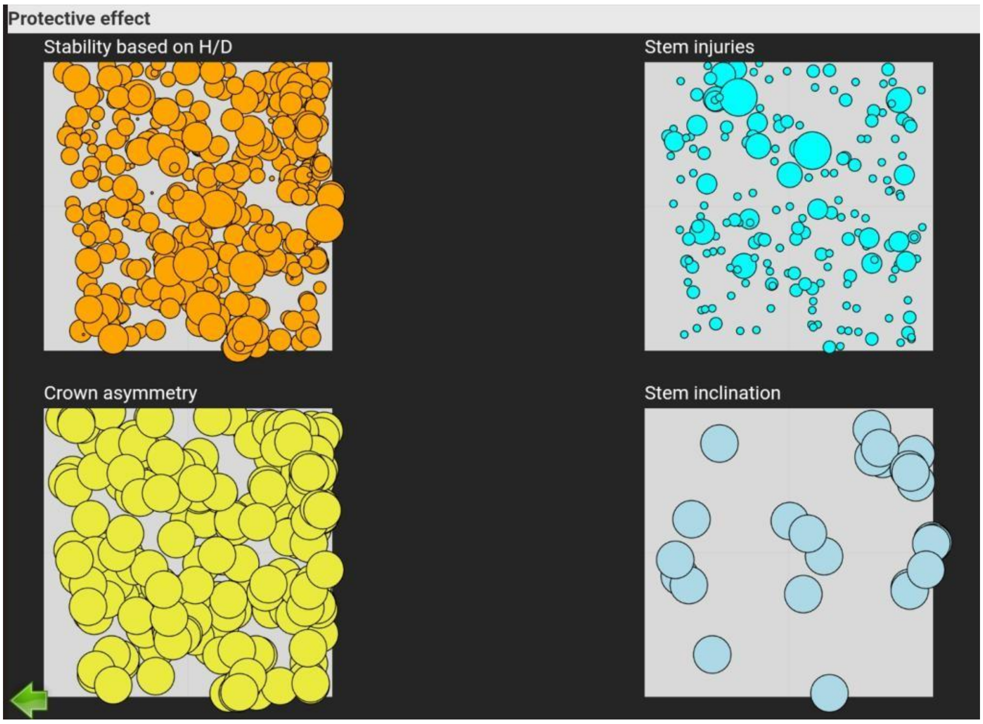


Figure 8: Spatial presentation of stability based on H/D, crown asymmetry, stem injuries and stem inclination. The size of each circle represents the magnitude of the corresponding value, with higher values represented by larger circles. Trees with very low or zero values are not displayed.

4. PROTECTIVE EFFECT INDEXES

Protective indexes developed in the ARANGE project (Cordonnier et al., 2014, Chapter 5 – Protection against Natural Hazards) are used in the I+ Trainer application to calculate the rockfall protection index, avalanche protection index, and landslide protection index (Table 2).

• **Rockfall Protection Index (RPI, %)**: The percentage of falling rocks stopped by the forest stand. It is calculated from structural and terrain-related indicators. Higher values indicate a higher level of protection.

• **PGIB (Basal interaction index)**: Estimates the effective basal area encountered by a falling rock. It is based on stem density, basal area, DBH, and rock size.

• **MNTI (Mean number of tree impacts)**: The expected number of trees hit by a falling rock, derived from stand structure and tree size distribution.

• **Avalanche Protection Index (API):** Measures the effectiveness of the forest in reducing avalanche risk. It is based on basal area, DBH, slope, and species composition. Values closer to 1 indicate a higher level of protection.

• **Landslide Protection Index (LPI, %)** - Indicates the effectiveness of the forest in reducing shallow landslides and erosion. It is based mainly on forest cover and stand structure; optimal conditions are associated with approximately 60% canopy cover.

Table 2: Protective indexes for protective effect assessment

Protective index	Data needed	Calculation/ description	I+trainer	Interpretation	Thresholds	References
Rockfall Protection Index (RPI, %) [illegible]	Structural and terrain indicators: stem density, stand basal area, DBH, slope, slope length, average rock diameter, rock density, initial fall height and share of deciduous tree species.	Estimation based on the ratio between the current energy dissipation capacity (CED) of the forest stand, and the dissipating maximal energy (DME) of falling rocks.	Displayed as a share of rocks being stopped by the forest stand (0–100%).	Higher values mean higher protective efficiency.	**> 90% very good protection** **75 - 90 % good protection** **50-75% adequate protection** **25-50% moderate protection** **< 25% ineadequate protection**	Cordonnier et al., 2014 Maringer et. al. (2016).
PGIB (Basal interaction index)	Stem density, stand basal area, DBH and average rock diameter.	Basal area that the rock theoretically and statistically encounters.	Displayed in m^2	Higher values indicate a higher protective effect.		Cordonnier et al., 2014
MNTI (Mean number of tree impacts)	DBH (cm) and average rock diameter (m).	Number of trees potentially and statistically impacted by the rock.	Displayed in number of trees.	Higher values may indicate a greater protective effect.		Cordonnier et al., 2014
Avalanche Protection Index (API) For pure evergreen stands then the formula for calculating the *API* is: $API = \min\left[\frac{G}{(0.2901 * \overline{DBH} + 1.494) \times (0.1333 * slope^{\circ} - 3)}; 1\right]$ For mixed and pure deciduous (including larch) forests (less than 70% of evergreen stems dbh>5cm) the formula for calculating the *API* is: $API = \min\left[\frac{G}{(0.528 * \overline{DBH} + 1.5566) \times (0.1333 * slope^{\circ} - 3)}; 1\right]$	Stand basal area, DBH, slope and share of deciduous trees.	Effectiveness of a forest stand in reducing avalanche hazard.	Index value 0–1.	Higher API values indicate better snow interception and greater avalanche protection capacity.	**Values closer to 1 indicate a higher protective effect.**	Cordonnier et al., 2014
Landslide Protection Index (LPI, %) We calculated our Landslide Protection Index (LPI) using forest cover (% projected canopy cover area: cannot be superior to 100%; all trees with a DBH ≥ 5 cm) only, as clear thresholds for stand stratification are not available: - Forest cover < 30%: LPI = low - Forest cover ≥ 30% and < 60%: LPI = medium - Forest cover ≥ 60%: LPI = high	Projected canopy cover area.	Effectiveness of a forest stand in reducing shallow landslide and erosion hazard.	Percentage-based stability index.	Higher values indicate better soil stabilization.	**Ideal profile** is a multi-layered forest with **60% canopy coverage.**	Cordonnier et al., 2014 SlideforNET.

4.1. Terrain and hazard features for calculation of protective indexes

The protective indicators used to describe terrain and hazard features for the calculation of the protective indexes are presented in Table 3.

• **Slope (°)** - The steepness of the terrain. Steeper slopes generally increase the probability and intensity of gravitational processes and reduce the overall protective efficiency of the forest (Table 3).

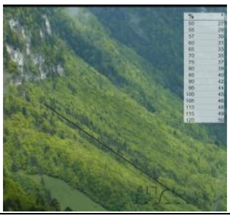
• **Slope length (m)** - The distance over which natural hazards (e.g. rockfall) can travel downslope. Longer forested slopes generally provide a greater opportunity for the forest to intercept and slow gravitational processes, thereby increasing its protective effect.

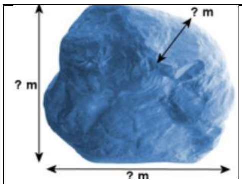
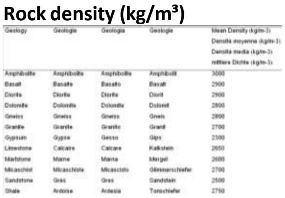
• **Average rock diameter (m)** - The average size of falling rocks that may occur at the site. Larger rocks have greater kinetic energy and are more difficult for the forest to intercept and stop.

• **Rock density (kg/m³)** - The mass per unit volume of the rock material. Higher rock density increases the kinetic energy and impact force of falling rocks.

• **Initial fall height (m)** - The height from which rockfall is initiated. Greater fall heights significantly increase the kinetic energy and potential impact of falling rocks.

Table 3: Protective indicators for terrain description (RockforNET)

Protective indicators	Field measurements	Calculation	I+trainer	Interpretation
Slope (°) 	Field measures or GIS.	Mean slope angle of the plot.	Fixed input parameter.	Steeper slopes increase hazard energy and reduce safety margin.
Slope length (m) 	GIS or field observation.	Distance from release zone to base.	Fixed input parameter.	Longer forested slopes provide greater interception of rock and snow movement.
Average rock diameter (m)	Field estimation or predefined scenarios.	Mean rock size used in simulation.	Input for energy calculation.	Larger rocks generate higher impact energy.

				
Rock density (kg/m³) 	Geological reference tables.	Standard density values per rock type.	Input for energy calculation.	Higher density increases kinetic energy.
Initial fall height (m) 	GIS or field observation.	Vertical drop from release point.	Fixed input parameter.	Higher release increases impact energy.

Geology	Geologie	Geologia	Geologie	Mean Density (kg/m-3) Densité moyenne (kg/m-3) Densità media (kg/m-3) mittlere Dichte (kg/m-3)
Amphibolite	Amphibolite	Amphibolite	Amphibolit	3000
Basalt	Basalte	Basalto	Basalt	2900
Diorite	Diorite	Diorite	Diorit	2900
Dolomite	Dolomite	Dolomite	Dolomit	2800
Gneiss	Gneiss	Gneiss	Gneis	2800
Granite	Granite	Granito	Granit	2700
Gypsum	Gypse	Gesso	Gips	2300
Limestone	Calcaire	Calcare	Kalkstein	2650
Marlstone	Marne	Marna	Mergel	2600
Micaschist	Micaschiste	Micascisto	Glimmerschiefer	2700
Sandstone	Grès	Gres	Sandstein	2500
Shale	Ardoise	Ardesia	Tonschiefer	2750

5. PROTECTIVE FOREST MANAGEMENT GUIDELINES

Protective forest management is guided by a set of general principles, that define the overall approach to maintaining and strengthening the forest's protective effect against natural hazards. Although these principles are broadly applicable, their implementation must always be adapted to local site conditions, stand characteristics, terrain, and the dominant natural hazards. When planning forest management in protective forests, the protective function of the forest must be considered the primary management objective. This means that the protection of infrastructure and human life is more important than timber production, and all silvicultural measures should be planned and implemented accordingly.

In the I+ Trainer application, these principles are translated into measurable changes in protective indicators and indexes, enabling users to evaluate how different silvicultural measures, such as thinning, species selection, or regeneration, influence the forest's protective effect. This approach supports evidence-based decision-making by linking field interventions with changes in the forest's protective capacity.

5.1. Silvicultural training with I+ Trainer on Marteloscopes in protective forests

Different tree selection strategies (e.g. selective thinning, heavy removal, or retention of stable trees) directly change the indicators and indexes (Figure 9 and 10):

• High retention of trees → increases stem density, basal area, RPI, and landslide protection.

• Heavy thinning → reduces obstacles, lowering RPI and increasing exposure to rockfall.

• Selective removal of unstable trees → improves stand stability, root system quality, and overall resistance.

• Retention of multilayered structure and high crown cover → maintains high API and LPI values in sensitive slopes.

Thus, every silvicultural decision immediately alters both structural indicators and protective indexes, allowing real-time comparison of scenarios.

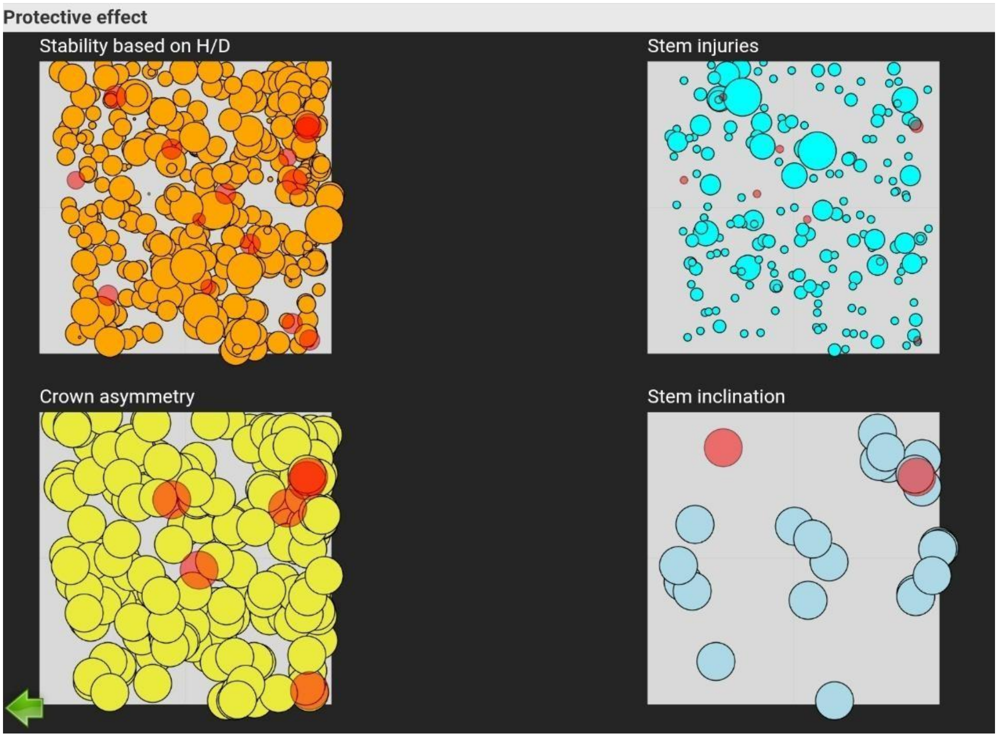


Figure 9: Map presentation of tree selection results (red circles – trees selected for removal). The size of each circle represents the magnitude of the corresponding value – higher values, bigger the circle. Trees with very low or zero values are not displayed.

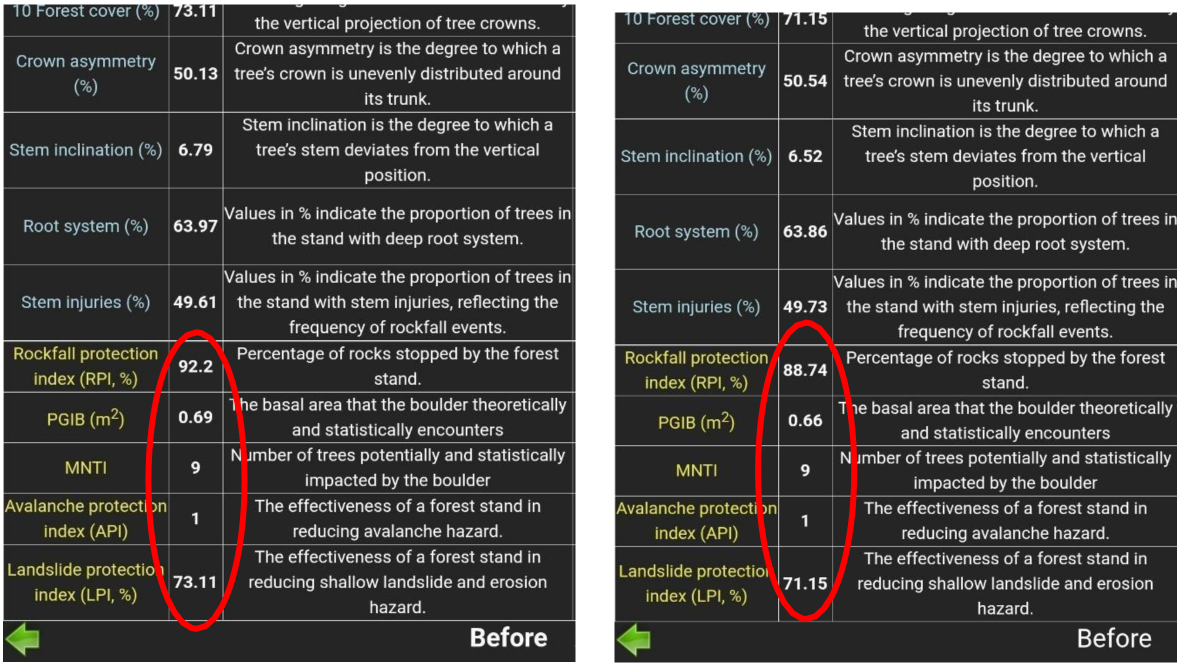


Figure 10: Protective indexes change in value before (left) and after (right) tree selection.

5.2. General principles for protective forest management

Protective forest management aims to maintain and enhance the capacity of forests to reduce the impacts of natural hazards such as rockfall, snow avalanches, landslides, debris flows, and soil erosion. The effectiveness of a protective forest depends on its structure, species composition, regeneration, vitality, and long-term stability. These characteristics are continuously influenced by natural processes, disturbances and climate change. Therefore, active management is often necessary to ensure that protective forests remain resilient and continue to provide reliable protection over time.

According to Mosaic deliverable Protective forest management in the Alps: an illustrated guide (Sever et al, 2026) management measures can be divided into <u>silvicultural measures</u>, which improve stand development and stability, and <u>biotechnical measures</u>, which stabilize disturbed sites and facilitate forest recovery. Silvicultural measures are the primary approach for maintaining the protective effect of forests, while biotechnical measures are applied when silvicultural interventions alone are insufficient to ensure slope stability and hazard protection.

Silvicultural measures

✓ Improving forest stand stability

Stand stability is essential for maintaining the protective effect of forests during disturbances such as strong winds, heavy snowfall, insect outbreaks, and rockfall events. This measure focuses on developing mechanically stable trees through appropriate thinning, maintaining favorable height-to-diameter ratios, promoting well-developed crowns and root systems, and ensuring continuous regeneration while avoiding large canopy openings.

✓ Improving tree species composition

Selecting site-adapted and climate-resilient tree species increases forest resistance to future environmental changes and disturbances. Mixed-species stands with deep-rooted species improve slope stability, enhance biodiversity, and strengthen the long-term protective effect of forests. Where necessary, enrichment planting and protection of regeneration from browsing are applied to maintain appropriate species diversity.

✓ Optimizing the spatial distribution of trees

The arrangement and density of trees strongly influence the ability of forests to reduce the energy of falling rocks, stabilize slopes, and prevent avalanche release. Selective thinning is used to achieve an evenly distributed trees while maintaining sufficient stand density and continuous forest cover.

✓ Forest gap management

Forest gaps are important for natural regeneration, but must be carefully managed in protective forests. Excessively large or poorly oriented gaps can increase the likelihood of rockfall, erosion, and snow avalanche release. Small, irregularly shaped gaps are therefore preferred, particularly on steep slopes, to maintain the forest's protective effect while supporting regeneration.

✓ Natural regeneration management

Natural regeneration ensures the continuous replacement of aging trees with individuals adapted to local site conditions. Management promotes regeneration by creating favorable light conditions through selective thining, protecting seedlings during operations, retaining seed-producing trees, and minimizing browsing damage. This approach supports long-term stand continuity, structural diversity, and slope stability.

✓ Active restoration through planting and seeding

Where natural regeneration is insufficient or absent, planting and seeding are used to restore forest cover and protective functions. Successful restoration requires careful species and provenance selection, appropriate planting techniques, protection against browsing, and regular monitoring. Retaining deadwood and using suitable microsites further improve seedling establishment and survival.

✓ Integrated deadwood management

Deadwood contributes significantly to the protective effect of forests by increasing surface roughness, slowing falling rocks, stabilizing snow cover, reducing erosion, and providing favorable conditions for natural regeneration. Management seeks to retain or strategically reposition logs, snags, and stumps while balancing ecological benefits with public safety near infrastructure.

Biotechnical measures

Biotechnical measures are applied where forest cover has been severely damaged or removed by disturbances such as windthrow, wildfire, bark beetle outbreaks, erosion, or landslides. These measures provide temporary slope stabilization and reduce erosion until vegetation becomes re-established and natural protective effect is restored.

✓ Slope stabilization with cuttings and seedlings

Live cuttings, particularly from willow species, and naturally regenerated seedlings are planted to establish vegetation rapidly. Their developing root systems bind soil particles, reduce surface erosion, and stabilize disturbed slopes while promoting long-term forest recovery.

✓ Slope stabilization with fascines and wattle fences

Bundles of living branches (fascines) and woven branch fences are installed across slopes to intercept runoff, trap sediment, reduce soil movement, and create favorable conditions for vegetation establishment. As the living branches root, they provide increasing biological stabilization over time.

✓ Stump management for protective function

Following harvesting or salvage logging, retaining high or strategically cut stumps helps preserve surface roughness, intercept falling rocks, and maintain protective effect. In some situations, low stumps are preferred to reduce rock rebound, depending on local hazard conditions.

✓ Logs on slopes

Logs are deliberately positioned across or at an angle to the slope to act as physical barriers against falling rocks and to reduce erosion. Anchored logs remain effective for longer periods and also create microsites that facilitate natural regeneration. On steep slopes, specialized harvesting techniques such as Alpi cut are used to retain logs and branches in positions that maximize their protective function.

Together, these silvicultural and biotechnical measures provide an integrated approach to maintaining the long-term stability, resilience, and protective capacity of forests while supporting biodiversity, ecosystem functioning, and climate change adaptation.

Further information on the silvicultural and biotechnical measures, including best practice examples of their implementation, is provided in the MOSAIC project deliverable "Protective forest management in the Alps: an illustrated guide", available online: https://dirros.openscience.si/IzpisGradiva.php?id=30407

6. ADDITIONAL TOOLS THAT CAN BE USED TO SUPPORT TRAINING IN PROTECTIVE FOREST MANAGEMENT

6.1. SAMSARA - A GROWTH SIMULATION MODEL

The Samsara2 forest simulator (Figure 11) is an individual-based and spatially explicit model (Courbaud & al., 2015) where individuals are classified as either saplings (diameter at breast height, DBH < 7.5 cm) or trees (DBH >7.5 cm). Tree and sapling demographic processes (recruitment, growth, mortality) are calculated for each year and for each individual. A key feature of the Samsara2 simulator is the integration of the SamsaraLight ray tracing model (Courbaud & al., 2003), which estimates the light intercepted by each tree and the light available on the forest floor for saplings. The Samsara2 model predicts the effect of forest management on the dynamics of several ecosystem services: wood production, biodiversity indicators based on tree microhabitats (Courbaud et al., 2021), protection against rock fall and snow avalanches (Dupire & aL., 2016). It is coupled to the Carbone balance model CAT (Pichancourt et al., 2018) and the economic library Economics2 (Ligot, 2021). These different simulation tools are modules of the software CAPSIS (Dufour-Kowalski et al., 2012).

An R package has been developed to connect the Samsara simulator to the field marking tool I+Trainer and simulate easily the consequences of the marking strategy (Figure 12). It imports field marking data from the I+Trainer, launches Samsara simulations over 50 years with a first thinning intervention corresponding to the field marking and following interventions mimicking a similar strategy, and then produces a simulation report with projections of the evolution of the marteloscope and associated ecosystem services.

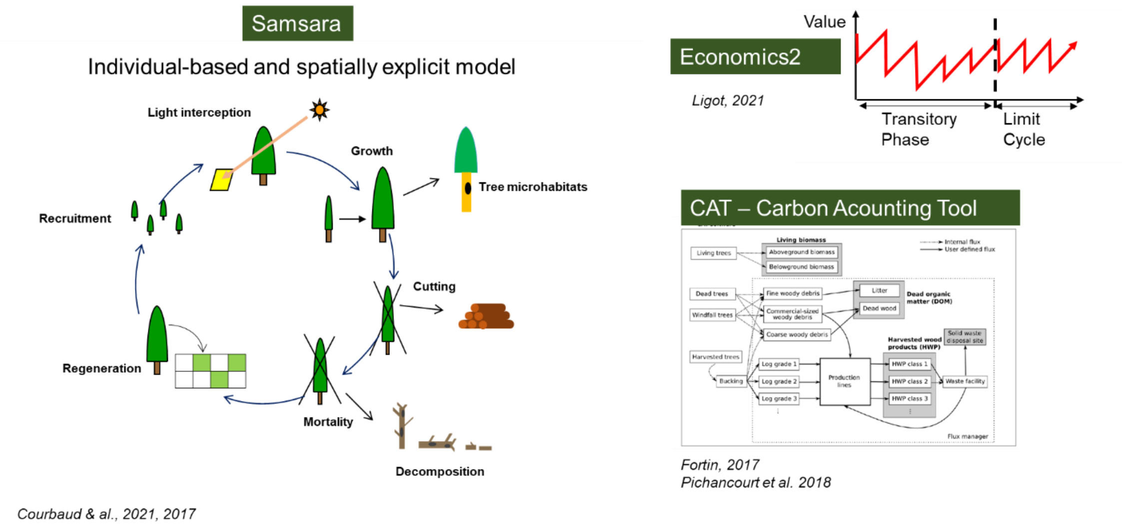


Figure 11: Principle of the Samsara model and of the associated libraries CAT and Economics2 in the software CAPSIS.

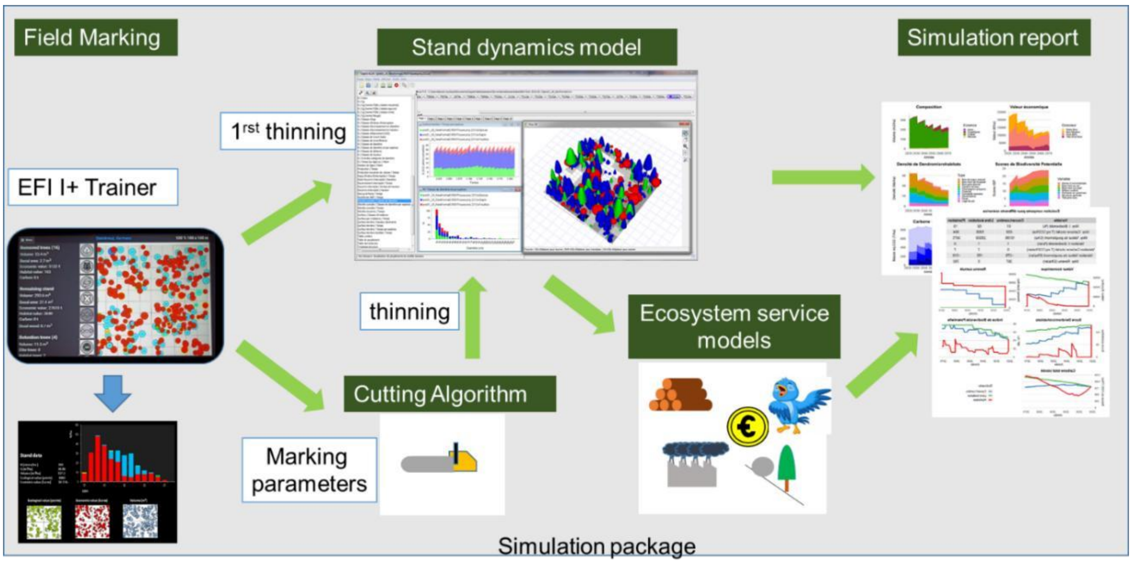


Figure 12: Principle of the R package connecting the I+Trainer field marking tool to the forest stand dynamics simulator Samsara

More information about the Samsara model and how it can be used is available at the CAPSIS platform: https://capsis.cirad.fr/capsis/home

6.2. RockforNET – a tool for quantification of the protective effect of forests against rockfall

The international EcorisQ (International association for natural hazard risk management) is a network of experts that promotes science-based and practical approaches to natural hazard risk management, particularly in mountainous regions. It supports the development of tools and methods for assessing and mitigating hazards such as rockfall, landslides, and avalanches.

RockforNET is one of its key tools, designed to quantify the protective effect of forests against rockfall. It simulates rock trajectories and energy in forested terrain and evaluates how forest structure, such as tree density, diameter, and spatial distribution, influences the ability of stands to stop or slow falling rocks. The tool is widely used to support evidence-based decision-making in protective forest management and risk assessment (Figure 13 and 14).

More information on EcorisQ and RockforNET is available here: https://www.ecorisq.org/rockfor-net-en

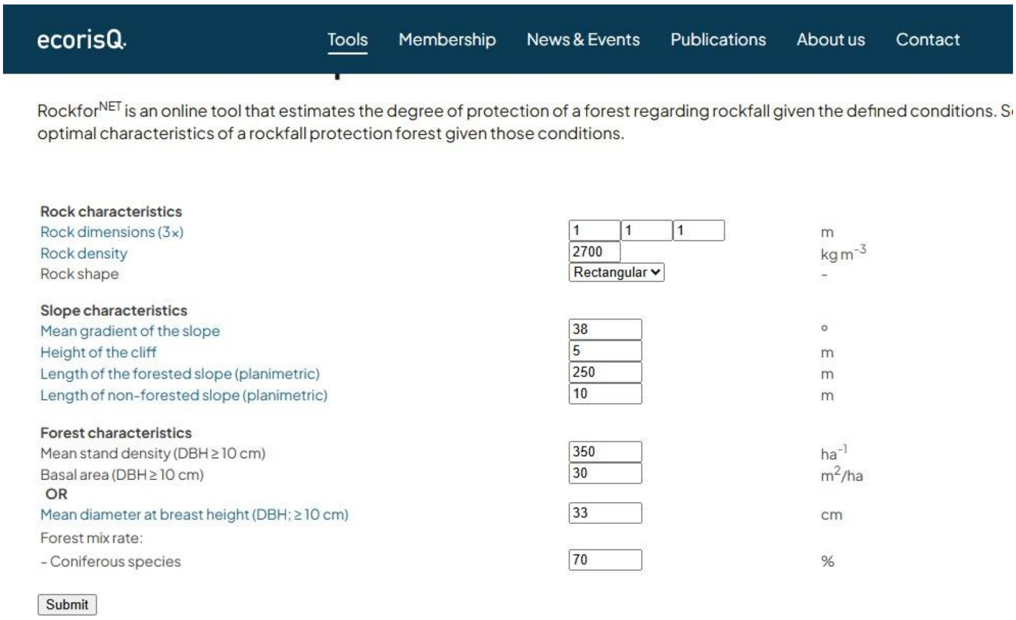


Figure 13: RockforNET tool within EcorisQ and its input parameters

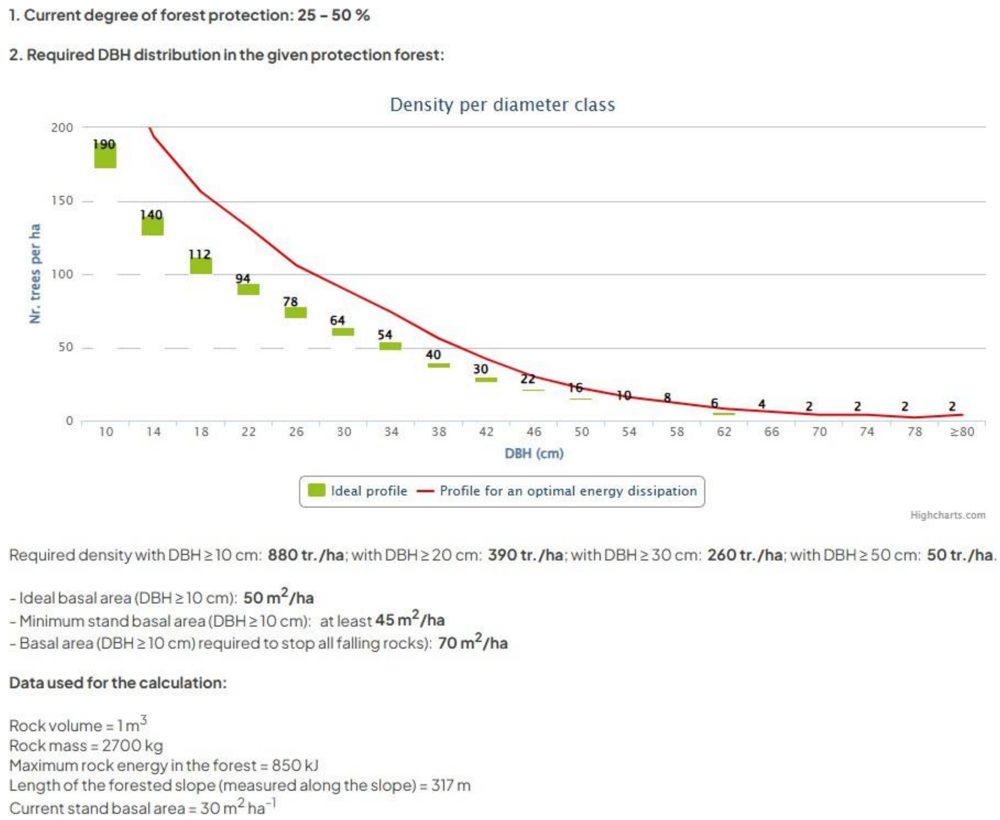


Figure 14: RockforNET tool within EcorisQ and its protective effect results

7. NINE STEPS CURRICULUM DEVELOPMENT PROCESS OF A PROTECTIVE FOREST MANAGEMENT TRAINING

Protective forest management training focuses on improving decision-making in forests where the protective function (protection against rockfall, erosion, and snow avalanches) is the primary management objective. **The target group** includes foresters, forest practitioners, and decision-makers. An optimal group size is up to **18 participants** to ensure effective interaction, discussion, and field-based learning.

Participants should work in small groups (e.g. three people per group), allowing them to discuss and justify the silvicultural measures they would apply to maintain or enhance the forest's protective effect. The training process should be guided by a trainer with expertise in protective forest management, who facilitates the discussion and helps participants interpret the results and evaluate the proposed silvicultural measures.

The following chapters describe the key steps for planning and conducting effective training in protective forest management.

7.1. DETERMINE TRAINING NEEDS

Training needs assessment identifies the gap between current skills and the required competencies for managing protective forests. For our training, this step means identifying whether participants are able to correctly interpret protective indicators and indexes (e.g. RPI, slope stability, root system development) and whether they can make appropriate silvicultural decisions that maintain or improve protective effect.

7.2. SPECIFY TRAINING OBJECTIVES

Clear objectives define exactly what participants should be able to do after training, avoiding uncertainty in learning outcomes. The main objective is that participants can evaluate and have knowledge on how to improve the protective effect of forests using silvicultural measures. What we want to achieve is improved decision-making for stability and hazard reduction. What we avoid is management that reduces forest protection (e.g. excessive thinning, loss of tree cover, or instability).

7.3. ORGANISE TRAINING CONTENT

This step defines the knowledge and information needed to achieve the objectives. In protective forest management training, content should include:

- Protective forest principles and management guidelines (e.g. Protective forest management in the Alps: an illustrated guide).
- Interpretation of protective indicators and indexes (RPI, API, LPI, etc.).
- Silvicultural strategies (restoration, tending, protection).
- Case-based decision-making in marteloscope plots.
- Consequences of different tree selection scenarios.

7.4. SELECT TRAINIG METHODS AND TECHNIQUES

Methods define how participants learn and interact with the content. Main methods in protective forest management can include:

- Field-based learning in marteloscope plots.
- Interactive decision-making using the I+Trainer.

- Additional simulations of the stand development for next 50 years, using Samsara.
- Group-based tree selection exercises.
- Scenario comparison (different thinning strategies).
- Guided discussion and result interpretation.
- Participatory planning exercises where participants develop and present management strategies.

7.5. IDENTIFY NEEDED TRAINING RESOURCES

This step defines all materials, tools, and organisational support required. Required resources should include:

- Access to equipped marteloscope plots with recorded data.
- Tablets with installed I+Trainer application (one tablet per group).
- Pre-loaded marteloscope datasets.
- Visual maps and datasheets to support field exercises.
- Trained group facilitators or leaders.
- Local forest professionals who know the area.
- Field plot infrastructure and safety setup.
- Facilities for indoor sessions and group work, coffee breaks and lunch.
- Tools for result analysis and group discussion.

7.6. ASSEMBLE AND PACKAGE PLANS

All elements (objectives, content, methods, and resources) are combined into a structured training. This means creating a clear step-by-step field training program, including timing, group division, exercise flow, and decision-making phases so the training runs efficiently and remains focused on protective forest objectives.

Each training day or module should be clearly planned. Lesson plans should include:

- Learning goals for each session.
- Key points to deliver.
- Field and classroom activities.
- Timing and materials.
- Safety protocols for fieldwork.

This allows for smooth delivery, clear structure, and flexibility for adaptation.

7.7. DEVELOP TRAINING SUPPORT MATERIALS

Support materials help explain content and guide learning during exercises. Materials include:

- Protective indicators' descriptions and interpretation sheets.
- Visual map of marteloscope plot.
- Visual aids, sylvicultural and management plans of the area.
- Instruction cards for tree selection tasks.
- Printed or digital summaries of protective forest guidelines.
- I+Trainer user guidelines (e.g. Protective forest management in the Alps: an illustrated guide).

7.8. DEVELOP TESTS FOR MEASURING TRAINEE LEARNING

Evaluation is used to assess learning outcomes and training effectiveness. This includes:

- Knowledge checks or practical tests (e.g. tree selection exercise).
- Group reflection on management choices.
- Short quizzes or guided discussions.
- Analysis of how different strategies affect forest stability.
- Participants' feedback should also be collected to improve future sessions.

7.9. TRYOUT AND REVISE TRAINING CURRICULUM

Before conducting a training, a pilot session should be organized to test a curriculum with a small group of participants. This pilot will help identify:

- Clarity and relevance of content
- Clarity of instructions.
- Group dynamics and timing.
- Realism of protective forest scenarios.

Based on feedback, the curriculum is adjusted to improve clarity, usability, and effectiveness in teaching protective forest management.

8. FIVE MAIN TRAINING PRINCIPLES

No. 0: Invitation for participants

A clear invitation defines when, where, why, and how the training will take place, including educational goals, program overview, trainer information, and required equipment. In protective forest training participants must be clearly informed, that the focus is on protective forest decision-making using marteloscope plots and I+Trainer, and that active participation in field exercises is required (e.g. tablets, field gear, group work).

No. 1: Effective start of training

At the beginning, the goals, program, and key logistics (timeframe, safety rules, structure) must be clearly explained. In protective forest training, this ensures participants understand that the goal is to evaluate and improve forest protective functions through silvicultural decisions, and how their choices will directly influence indicators, such as stability and slope protection.

No. 2: Put your knowledge into wider frame

New information must be connected to real forest systems and broader ecological and management contexts. This means linking marteloscope exercises to real-world issues such as rockfall protection, climate change impacts, forest stability, and infrastructure safety, so participants understand the relevance of their decisions beyond the training plot.

No. 3: Cut your educational content into digestible snacks

Training content should be divided into small, clear, and manageable units that participants can easily understand, apply, and build upon step by step. In protective forest training, complex topics such as protective indicators, forest stability, and management scenarios should not be presented all at once. Instead, they should be broken down into short learning steps (e.g. understanding stand structure first, then hazard conditions, then interpreting rockfall and landslide indexes, and finally testing management options in i+Trainer). This step-by-step approach helps participants gradually develop the ability to make informed decisions in protective forest management without being overwhelmed.

No. 4: Practice, practice, practice (10% read; 20% heard, 30% seen, 50% heard and seen, 70% said and repeated, 90% of done)

Learning is most effective through active participation and repeated application (seeing, doing, and discussing). In protective forest training, participants see, perform and discuss:

- Tree selection in marteloscope plots.
- Simulation of different thinning scenarios.
- Analysis of changes in protective indexes.

This shifts learning from theory to hands-on decision-making in real forest conditions.

No. 5: Evaluation is a crucial part of training

Evaluation measures how well participants understand and apply knowledge, and how training can be improved. In protective forest training, evaluation focuses on:

- How participant decisions affect protective indicators (h/d ratio, stem density, basal area etc.) and indexes (RPI, LPI, API).
- Comparison of alternative management strategies.
- Group discussion on balancing forest stability and management interventions.
- Feedback for improving future training design.

These principles ensure that protective forest training is clear, practical, and decision-oriented, enabling participants to develop real competence in managing forests where protection functions are the priority.

9. EXAMPLE ON HOW TO CONDUCT A PROTECTIVE FOREST MANAGEMENT TRAINING WITH I+TRAINER APPLICATION

PREPARATION PLAN BEFORE TRAINING

- ✓ **Prepare and charge tablets**
- ✓ Ensure that all tablets are fully charged, functional, and ready for field use. Each tablet should be labelled with a number so that each group can easily identify its assigned tablet.
- ✓ **Install the latest version of I+Trainer application**
- ✓ **Download and upload the marteloscope dataset**
    - Ensure that the correct marteloscope files and training data are available on each tablet.
- ✓ **Test system functionality**
    - Check whether the application, data access, GPS, and file export functions operate correctly. In case of technical issues, contact the system manager in advance.
- ✓ **Prepare PDF merging procedure**

- Ensure familiarity with combining exported PDF files into a single comparison document after the exercise.

✓ **Check possible integration with Samsara model**
- Verify whether connection with the Samsara platform is possible and prepare a short explanation of its purpose and functionality for participants.

✓ **Provide data transfer equipment**
- Prepare the necessary cables or adapters for transferring data between devices if required.

TRAINING PROGRAM SCHEDULE

Start	Duration	Activity	Goal	Materials	Notes
07:00	1 hour	**Introduction to the topic and methodology**	Introduction of the protective forest management, overall training approach, including marteloscope concept, i+Trainer application, protective indicators, and general guidelines of the educational concept.	Presentation materials, guidelines	Participants gain theoretical understanding of the field exercise.
08:00	30 min	**Introduction to the study area and marteloscope plot**	Introduction of the site, current management challenges, management goals.	Printed materials, silvicultural plan	Participants get knowledge on the condition and silvicultural goals at the specific site.
08:30	30 min	**Tablet familiarization session**	Introduction of the I+ Trainer on tablet computers. To allow participants to explore the tablets independently, test the application, and clarify potential questions. File saving procedure (PDF and CSV) and Wi-Fi requirements introduced.	Tablets with I+Trainer application	Encourages active learning and technical familiarity.
09:00	30–60 min	**Coffee break & transport to the marteloscope site**	Informal break allowing participants to process information and reflect on management objectives.	—	Includes transport to the marteloscope site.
10:00	15 min	**Field introduction at the marteloscope site**	Presentation of plot layout, interpretation of tree numbering system, and explanation of “snake-like” movement through the plot for safety in steep terrain, reducing exposure to rockfall and similar hazards. Overview of main forest stand objectives (Figure 15.)	Field site	On-site orientation is required. ***Safety when moving across the plot is top priority.*** If steep terrain or hazard conditions do not allow safe access, the activity must not be carried out.
10:15	15 min	**Group assignment**	Random allocation of participants into groups (1–5). Transition to starting positions at the top of the plot in case of steep terrain.	Group labels, tablets	Participants are divided into ***random groups, which ensures balanced group distribution***.
			Practical field exercise where participants		

10:30	2 hours (approx.)	**Marteloscope training exercise**	assess trees and apply methodological principles (Figure 16 and 17). Trainers supervise, rotate between groups, and provide support when needed.	Tablets, field equipment	***Duration may vary depending on plot conditions***.

Start	Duration	Activity	Goal	Materials	Notes
12:30	—	**End of field exercise**	Verification that all data are saved correctly (PDF and CSV). Collection of tablets and completion of fieldwork.	Tablets	Data integrity check.
13:00	1.5 hours	**Lunch break**	Rest period and informal discussion. Trainers consolidate and merge collected data for comparison and prepare analytical outputs (pdf with results and Samsara simulations).	Restaurant / external venue	Preliminary data processing (e.g. file merging, software testing, possible Samsara simulations).
14:30	1 hour	**Group discussion and interpretation of results**	Presentation and discussion of participant decisions and results, comparison of results, and feedback from trainers.	Presentation materials, results	Focus on reflection and learning outcomes.
15:30	—	**End of program**	Closing remarks and completion of training session.	—	Training ends.

Figure 15: Introduction to the area during a Marteloscope Soteska training

Figure 16: Training in groups on a marteloscope plot

Figure 17: I+trainer application usage during training

10. CONCLUSION

The MOSAIC educational concept improves understanding of protective forest management by linking theory with practical field application. It provides a simple and structured way to assess forest protective functions against natural hazards. The concept is useful in training and practice because it supports consistent decision-making and can be applied in education and professional forest management. It is a helpful document for anyone who wants to lead or participate in training activities for protective forest management, as it supports clear communication and effective learning.

When trying out a training you need to

… remember to always KEEP IT SIMPLE …

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