

ROCK THE ALPS

Synthetic guidelines

Interreg
Alpine Space



ROCK the ALPS 
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*Synthetic guidelines for sustainably manage rockfall protection forest ecosystem service in
the AS*

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ERSAF – Regional Agency for Services in Agriculture and Forest - Lombardia Region

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BMLFUW – Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management

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ASP 462 – RockTheAlps

Interreg
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Synthetic silvicultural and
forest management
guidelines for sustainably
manage rockfall protection
forest ecosystem services



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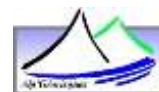
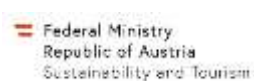


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PREFACE

This synthetic handbook aims at providing the basic information related to the sustainable management of protection forest against rockfall hazard, through their definition, assessment and the evaluation of future threats due to the ongoing global change.

The manuscript includes information derived from the Interreg Alpine Space project “Rock The Alps”. For this reason, the reported indications often refer to the specificity of the Alps, but can be extended to many mountain regions of temperate areas. All the material produced over the three-year lifetime of the project can be downloaded at the Download section of the project’s website: www.alpine-space.eu/projects/rockthealps/en/home .



1 PROTECTION FORESTS

1.1 Definition

Protection forests have always been a relevant feature of mountainous areas, where they provide protection not only to residential areas, but also to transportations and economical activities. In recent times this function has even increased in importance, due to the construction -mainly for tourism- of new settlements in remote valleys with the necessity of year-round access to them (Wehrli and Dorren 2013; Lingua et al., 2017).

All forests provide a protective function, not only in the mountains: they reduce soil surface erosion and they contribute directly and indirectly to the hydrological cycle.

Protection is one of the principal functions ensured by a forest stand. Nonetheless, not all forests are defined as protection forests: in order to be so, they must protect against one specific natural hazard, and their preeminent function must be the protective one, not excluding other functions that may secondarily be present.

The most common natural hazards against which protection forests exert their role are gravity-driven abiotic disturbances, such as snow avalanches, surface erosion, debris flows, shallow landslides and rockfalls. In this regard, protection forests are of the utmost importance in mountainous regions, where steep slopes increase the probability of these natural hazards (Lingua et al., 2017).

The protective function can be active or passive, the first type occurring when the forest contributes to impede the abiotic disturbance to take place, the second one when the forest stand mitigates the negative effects of the disturbance. These two types of protection depend greatly on the natural disturbance in question, for example, forests can actively protect against snow avalanches if they are present in the release zone (where the avalanche starts), but they can only give passive protection in front of rockfalls, reducing the number and the kinetic energy of rocks that arrive at the foot of the slope.

A second distinction is made between direct and indirect protection forests (Brang et al., 2006): direct protection is provided to particular assets or communities that lie adjacent to the forest (e.g. downslope), indirect protection is provided more generally to all assets and communities over a broader scale independently from their specific location.

Therefore, not all mountainous forests interested by gravity-driven hazards provide direct protection, but only those that protect a limited number of people, structures or infrastructures located below and near them, such as the case of a group of houses or a road protected from snow avalanches by an above forest stand.

Almost all forests, instead, can provide some indirect protection. In mountainous areas, for instance, forests can indirectly protect the bottom of the valleys from flooding by regulating



the climate at landscape level, by intercepting precipitations and by protecting the soil from erosion.

The type of protection provided by a forest greatly influences its management. In particular, direct and indirect protection forests will have different management targets and intervention priorities when it comes to forest planning (Berger and Rey 2004).

In fact, direct protective forest stands must constantly fulfil their role (Lingua et al., 2017) and this can only be achieved through active forest management, in order to give the stand its efficiency characteristics: a high persistency and a high resistance to natural hazards (Lingua et al., 2020).

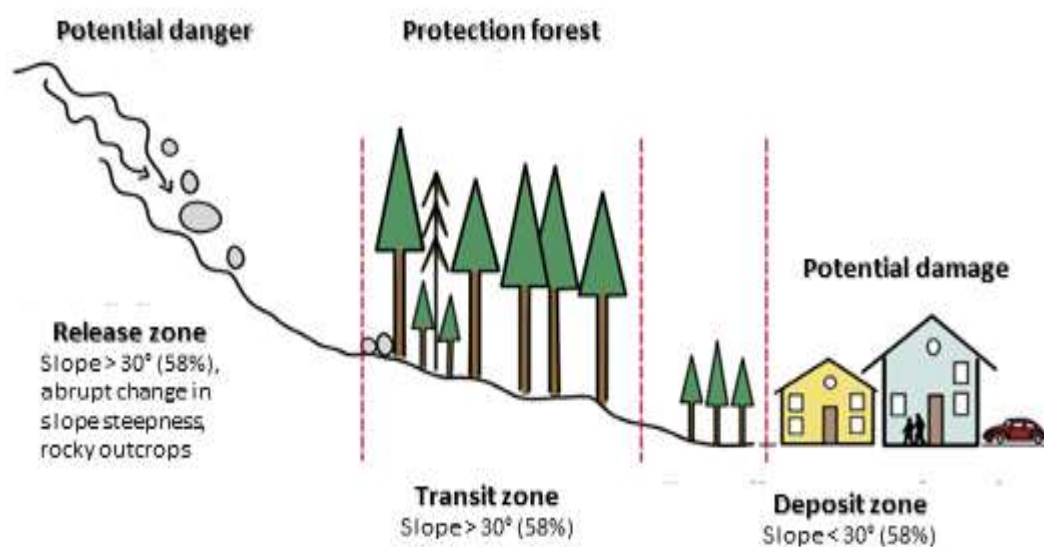


Figure 1: Distinctive areas in the rockfall processes (Regione Autonoma Valle d'Aosta - Regione Piemonte, 2011; mod.).

1.2 How to identify protection forests

The identification of forests that potentially play a protective role against rockfall hazard can be achieved adopting empirical methods based on data from past events. Several tools are available for modelling and simulating rockfall events (see Chapter 2.2), and they work quite well at the local (slope, forest) or regional scale but often they are not completely suitable for being applied over a large area since computational and data availability constraints arise.

Considering the Alpine Space, covering a surface of 390.000 Km², a new model had to be implemented in order to achieve a fast and harmonized mapping of protection forests.

For this purpose, in the RocktheAlps project a new model named ROCK-EU able to work at the Alpine space scale, has been set up.

The spatial data used as input in ROCK-EU were selected in order to be homogeneous over the whole Alpine Space, freely available (open-access), and relatively constantly or regularly updated. These data were obtained from the European Union's Earth Observation Programme Copernicus and from OpenStreetMap, and specifically:

- **Relief and topography** were derived from the EU-DEM v1.1 which is a digital terrain model (DTM) available in raster format for Europe at 25m spatial resolution with an overall vertical accuracy of 2.9 meters RMSE. EU-DEM was used to account for relief and topography in the modelling process;
- **Land and forest cover** were extracted from Corine Land Cover (CLC) 2018;
- **Water surfaces and rivers** were obtained from OpenStreetMap contributors in shapefile format;
- **Human assets** were derived from OpenStreetMap considering three categories: railways, buildings and main roads.

The model produces two main outputs. The first one dealing with the number of passing rocks (PR in Figure 2) is related to the rockfall hazard and consists of a map (shapefile derived from a 25 m resolution rasters) showing the areas interested by the passage of the simulated blocks. A distinction is made in the attribute table between propagation coming from blocks released from areas detected using a slope threshold of 42° and a slope threshold of 28° (specific for the pixel resolution). The purpose of this layer is the identification of forests with a potential protective function, and therefore is not intended to be used for hazard zoning or risk assessment.

The second output of the model is the map of forests that have a potential protection function (PF). The layer returns the areas of forest that have a potential protection function. As for the rockfall hazard, a distinction is made in the attribute table for protection forests mapped using block released areas of 42° or 28° .



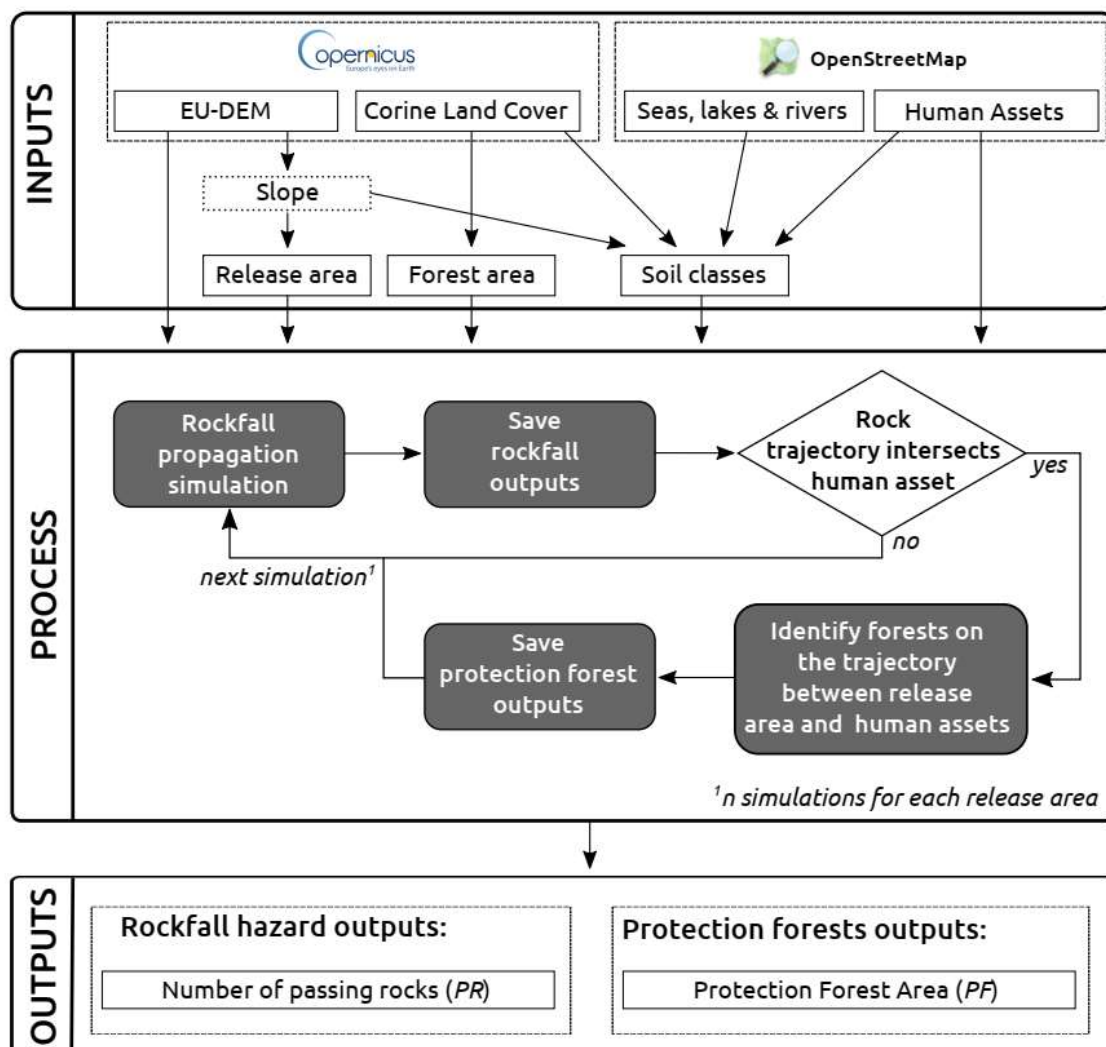


Figure 2: General workflow used for the harmonized mapping of protection forests (ROCK-EU model).

2 ROCKFALL MODELLING AND MONITORING

The modelling of rockfall events and the following monitoring process require first the characterisation of the typical topographies, the analysis of past events and then the choice of the best modelling approaches and tools.

2.1 Characterisation of the Alpine Space

Typical Alpine Space topographies were determined based on the altitudinal zonation of vegetation in the Alps. Each zone are characterized by specific vegetation and climate features which can greatly affect the presence of a rockfall source areas (release of rock material), and the characteristic of the transit and deposition zones (presence of forest vegetation or not). The most striking change in vegetation that is affecting rockfall processes is concerning the forest cover, being its absence a lack of obstacles able to reduce the rocks velocity (energy) or eventually able to stop the rocks. In order to differentiate the Alpine space according to the vegetational and altitudinal features, we can identify four different areas based on the following categories (Figure 3):

- **Foothill zone (deciduous forest):** 0 – 900 m on north-faced slopes, 0 – 1100 m on south-faced slopes;
- **Montane zone (mixed forest):** 900 – 1500 m on north-faced slopes, 1100 – 1700 m on south-faced slopes;
- **Subalpine zone (conifer forest):** 1500 – 2200 m on north-faced slopes, 1700 – 2400 m on south-faced slopes;
- **Alpine zone (Alpine meadows):** 2200 – 2900 m on north-faced slopes, 2400 – 3000 m on south-faced slopes;
- **Nival zone (Moss and lichens):** > 2900 m on north-faced slopes, > 3000 m on south-faced slopes;



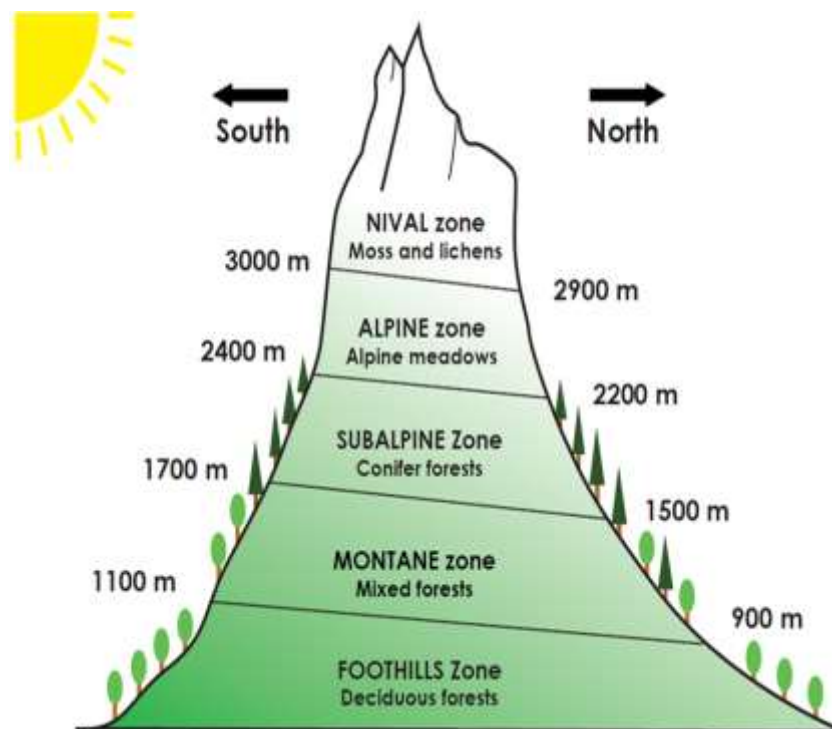


Figure 3: Altitudinal zonation used for categorization of typical topographies in Alpine Space
(Source: University Grenoble Alpes, 2018).

Zones were determined by the altitudinal features using a digital elevation model with spatial resolution of 25 m (DEM-EU v1.1 Copernicus, 2016) and separate altitude categories were based on the slope's aspect (north or south slopes).

2.1.1 The database of rockfall events

During the field campaign, 1924 rockfall source areas and corresponding 5674 rockfall deposit areas were collected throughout the whole Alpine Space (Figure 4). Part of the features were collected using ArcCollector, an application for smartphones that designed for collecting field data. A specific collection form was defined for historic rockfall events (see deliverable “D.T1.2.1 Database on historic rockfall events”), while additional data were provided by different data sources coming from several institutions.

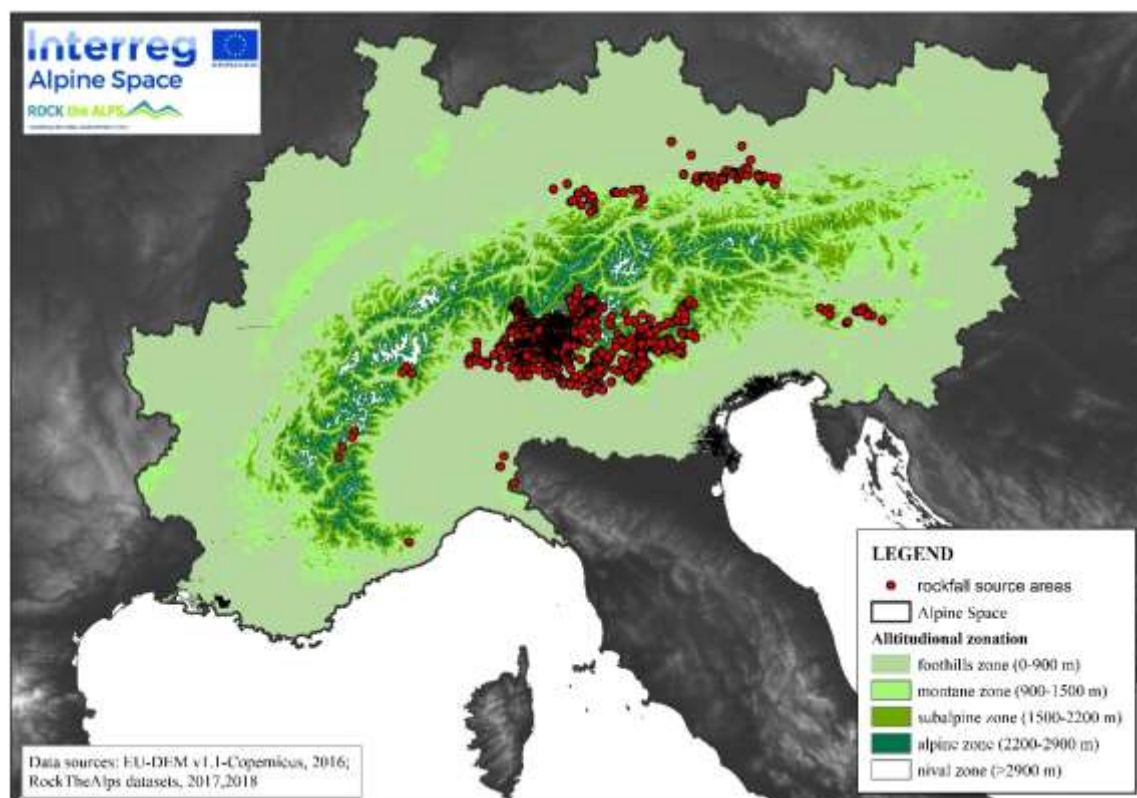
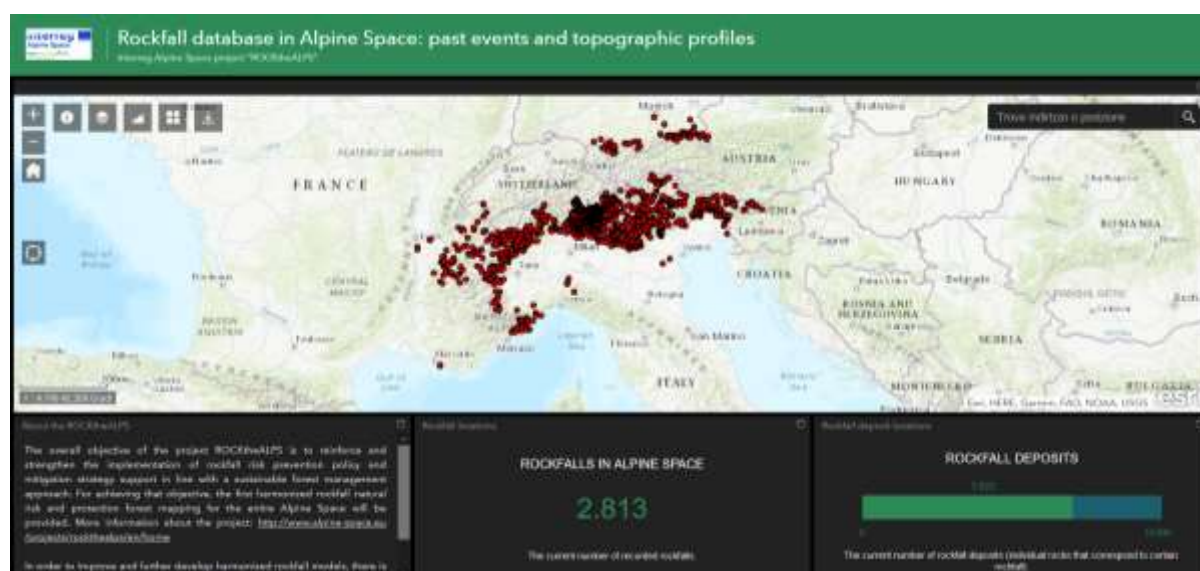


Figure 4: Altitudinal zonation of Alpine Space and locations of rockfall source areas included in the project's database.



According to the available data (Figure 4), the majority of rockfall sources is located in the lower three altitudinal zones: the subalpine zone, montane zone and foothill zone. Nevertheless, the average altitude of rockfall source areas is 1455 m.a.s.l. while their average slope value is

25.6°, with a prevailing exposure towards west. The most common rockfall source type is rock cliff and 51% of rockfall those sources is located outside of the forest.

For what concerns rockfall deposits, the majority is located in the montane altitudinal zone with no deposits located in the nival zone. The average altitude of rockfall deposit areas is 1255 m.a.s.l. . The average slope value of rockfall deposits is 17.8° and the prevailing slope aspect west. The average length of run-out zone was 249 m and the most rocks stopped at an energy line angle between 47° and 52°.

Based on the deposit areas identified in the field, the most rocks are characterised by undefined shape, followed by rectangle and spherical shape. The volume of individual rockfall deposit was calculated based on the rock's dimensions and corrected by the factor shape (disc = 0.7, ellipsoidal = 0.7, rectangular = 0.8, spherical = 0.6, undefined shape = 0.7). The average the rock volume was 2.206 m³.

Among the main factor at the origin of rockfall deposits, it has been possible to identify the presence of other rocks (2.992), followed by undefined/normal stop (380) and tree hits (236). Finally, different infrastructures and roads stopped approximately 10 rocks each category. 74 % of rockfall deposits stopped and deposited outside of the forest area and 26 % inside the forest area. The average DBH of trees that stopped rocks was 31 cm, with minimum DBH being only 4 cm and the largest 70 cm.

A detailed analysis of the AS events can be found in the deliverable named “D.t1.4.1 Harmonized data for rockfall risk assessment at the as scale” on the project website.

2.2 Approaches

The Alpine range is characterised by a really diversified morphology and several geologic substrates, factors that provide for a plethora of cases for the study of rockfall events. In order to analyse and understand the variability of such processes, many softwares are used for 2D/3D simulation and modelling purposes. A shortlist of the tested ones includes:

- **Rockyfor3D**, a simulation model that calculates trajectories of single, individually falling rocks, in three dimensions (3D). The model combines physically-based, deterministic algorithms with stochastic approaches, which makes Rockyfor3D a so called ‘probabilistic process-based rockfall trajectory model’. Rockyfor3D can be used for regional, local and slope scale rockfall simulations. This approach has been used in the case studies of Colcuc, Cogolo and Cesana Torinese (see Appendix 2: Case studies).
- **Platrock**, is an online platform available on the project’s website and open to further development that aims at the creation of a unique access point for the deployment of 2D/3D simulation models and online processing.



- **HY-STONE**, a software for the simulation of rock trajectories using a multi-scale stochastic approach. Particularly suitable for high-resolution terrain models, it models free fall, impact with vegetation, fragmentation processes and rolling with different damping coefficients. This approach has been used in the case study of Cevo (see Appendix 2: Case studies).

2.3 Spatial resolution of digital elevation model

When assessing the area potentially affected by rockfalls, the modelling process has to account for the working scale and therefore which spatial resolution of the digital elevation model (DEM) should be used. Usually high spatial resolution provide more details and a realistic representation of the surface topography. However, when considering the spatial extent of the entire Alpine Space, choosing the highest spatial resolution available might be too precise for modelling purpose since on a map of this extent many detailed features might not be seen.

For this reason, the influence of the resolution of the digital terrain model on rockfall modelling has been analysed in order to find the most suitable DEM at the AS level. In the study, five spatial resolutions of DEM (1 m, 5 m, 12.5 m, 25 m and 100 m), available for Slovenia, were used for modelling rockfall source, transit and deposit areas. Rockfall source areas were defined in a geographical information systems by using threshold values related to the DEM spatial resolutions (Arpa et al., 2008), while rockfall transit and deposit areas were modelled using the empirical model implemented in the software CONEFALL (Jaboyedoff and Labiouse, 2003).



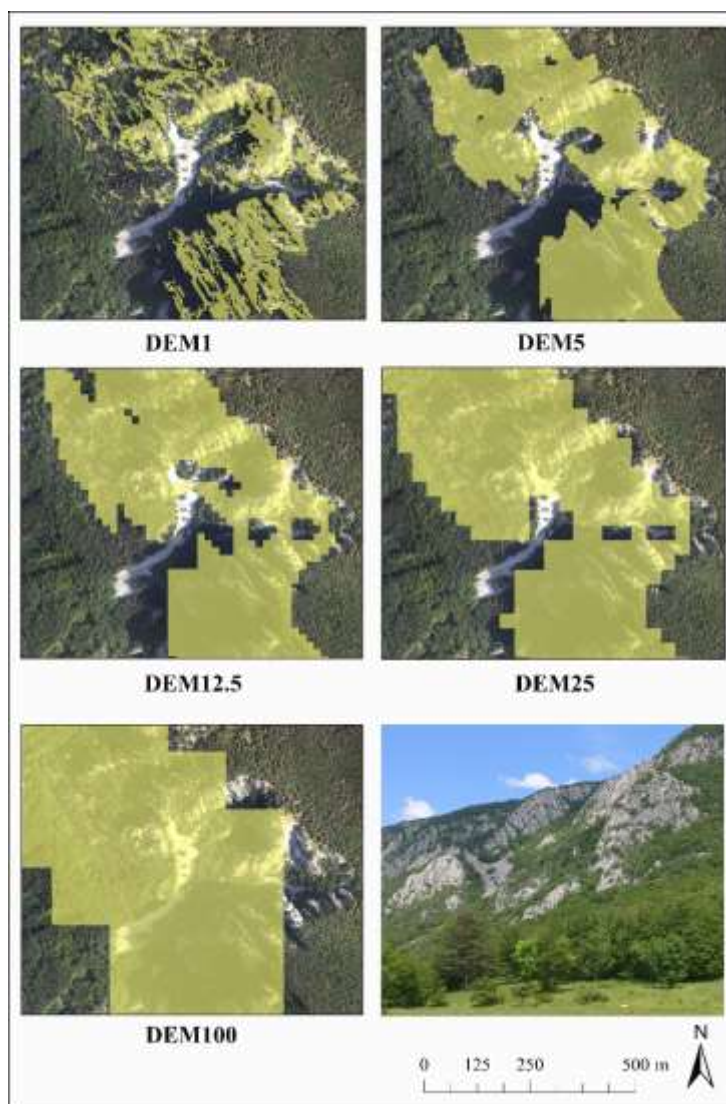


Figure 5: An example of a modelled rockfall source at different spatial resolutions.

When comparing rockfall source areas among different spatial resolutions, it can be noticed that location of source areas are comparable, but their size linearly increases when reducing the spatial resolution. This results in a higher probability of falsely delimited rockfall source areas, with some delimited areas may not be the actual sources or part of the transit and deposit area may also be missing (Figure 5). The confusion matrix analysis shows that compared to the DEM1, DEM5 and DEM12.5 have the highest accuracy rate when predicting source areas, while DEM100 has the lowest. The most precise spatial resolution is 1 m where even the smallest sources are correctly recognized and delimited. The disadvantage of this spatial resolution is that it recognizes even the smallest changes in the surface slope, consequently some false source might be defined, especially at these locations: near anthropogenic objects, along the riverbanks, in areas of permanent crops, in sinkholes and along artefacts of the DTM.

The largest transit and deposit areas are common to all spatial resolutions, and all spatial resolutions have the common areas of highest risk of rockfall hazard, with the only difference is that at higher spatial resolutions those areas are more restricted, while at coarser spatial resolutions are more extensive (Figure 5). Some rockfall transit and deposit areas are missing at lower spatial resolutions compared to the higher spatial resolution due to the missing rockfall sources in the lower resolutions. In brief, spatial resolution 1×1 m covers the largest area that is delimited as rockfall transit and deposit areas. The confusion matrix analysis shows that, compared to DEM5, all spatial resolutions have similar accuracy of prediction, with the highest probability of correct prediction with DEM5 and DEM12.5 and the lowest with DEM100.

The highest number of source, transit and deposit areas is found with DEM1, and these areas also have the smallest surface area compared to other spatial resolutions. The number and the surface area of those individual rockfall areas decrease with the spatial resolution of the DTM. The longest runout distance of rockfall deposit area is obtain with a spatial resolution of 100×100 m and it deviates largely from the other spatial resolutions. The length of the maximum runout areas is quite similar among the higher resoulutions DEMs (DEM1, DEM5, DEM12,5).

The computation time required by the modelling process has proved to be a key factor when choosing which spatial resolution of the DEM should be used to model rockfalls. The time comparisons between different spatial resolutions showed significant differences in modelling rockfall transit and deposit areas, while there were no major deviations in modelling rockfall source areas. The number of rockfall source raster cells will have the largest impact on the modelling time of rockfall runout zones, and a larger number of source cells will result in a longer modelling time. In fact, the modelling time was the longest for spatial resolution 1×1 m, and it is by 99 % shorter for other spatial resolutions (Figure 6).



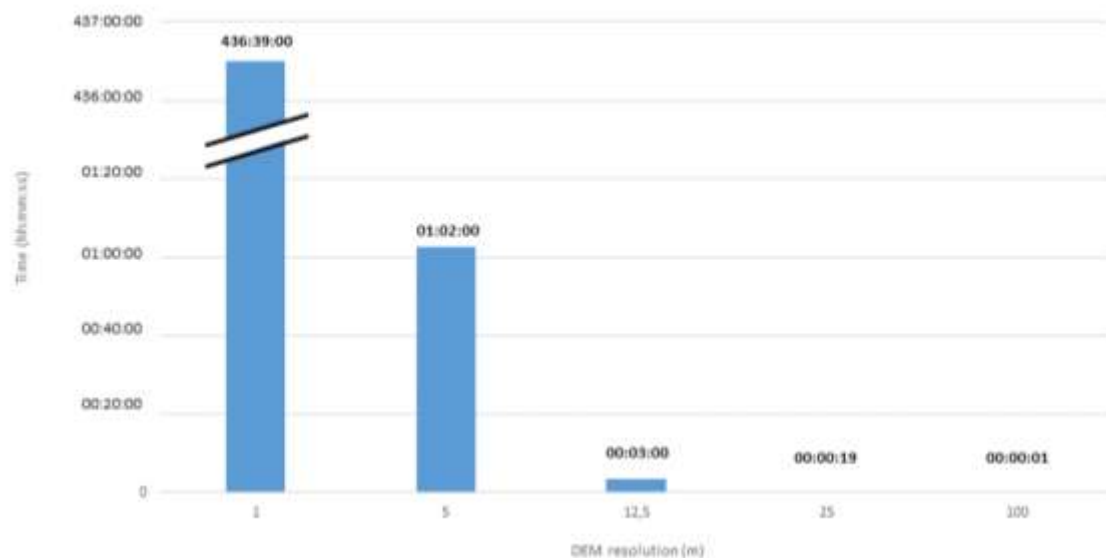


Figure 6: Modelling time for rockfall transit and deposit areas for different spatial resolutions.

Based on these findings it is recommended that a spatial resolution of 100 m is not used for modelling rockfall source areas as this resolution is too coarse for modelling this kind of geomorphic process, while spatial resolutions of 1 m, 5 m, 12.5 m and 25 m are appropriate for modelling rockfalls at different scales. It is recommended to use:

- spatial resolution of 1 m or closer at local level, where modelling results will be used for accurate assessment of rockfall risk at the level of individual buildings and infrastructure. Several studies suggest that 2 m resolution is a good compromise between accuracy and computational load,
- spatial resolution of 5 m at the local administrative unit (LAU 2) level, where modelling results will be used for the assessment of rockfall risk at settlement level and the accuracy is not as important as in the previous case,
- spatial resolution of 12.5 m and 25 m at regional and national level, where the purpose of rockfall modelling is to provide a general overview of rockfall risk at larger areas, and the results are still comparable to higher spatial resolutions.

Based on the available DTMs in all Alpine countries, the most appropriate spatial resolution to use at the Alpine Space level has been 25 m.

Advanced support systems

Environmental sciences are widely benefitting in the recent years of the technological innovations that the market is providing day by day at lower prices.

The large availability of economically affordable tools is changing the way many field-based disciplines are tackling their main objective. Field operations are now supported by a wide range of ancillary data at really high-resolution. In the specific case of protection forests against rockfall events, drones proved to be an effective support capable of providing aerial photographs with centimetric resolution from which can then be derived further information (DTM, DSM, etc.) through the application of photogrammetry.

Highly detailed surveys can include laser-based sensors such as airborne or terrestrial LiDAR. This technology is capable of describing the 3D structure of objects by means of a laser pulse scanner. Its use can hence provide a detailed insight on the ground on forested slopes at landscape scale as well of being capable of extremely detailed scans of rock walls or forest stands, from which then extract the required parameters.

A wide range of remote sensing applications supporting the study of rockfall events can be found in the study cases reported in Appendix 2.





Figure 7: Drones are becoming a common tool for rapid surveying.



3 THE ROLE OF PROTECTION FORESTS AGAINST ROCKFALL HAZARD

3.1 Ecology and management

The management of protection forests can nowadays take advantage of a quite wide knowledge raised in the last two decades, even if some issues still need to be fully understood. The researches have been mainly carried out within the Alpine territory due to its peculiar and dense interface between environment and human activities. The research provided new insight on the natural hazards mechanisms and the inter-relationships with forest stands, supplying new tools and advices for a quantitative and sound approach to the topic.

The most important parameter that affect this natural hazard is the slope. A rock can be released and start moving when slope steepness is greater than 30° . If the slope increase, rocks can assume different trajectories and movement types:

- under 30° = sliding movements
- between 30 and 35° = rolling movements
- over 35° = bouncing movements

As common thresholds to define the effectiveness of a forested area, two parameters can be taken into account: planimetric length preferably longer than 200 metres and average rocks' size below 5 cubic metres. In other cases, the presence of forest stands is considered scarcely effective or inefficient. On the other side, as aforementioned, if the slope suddenly decreases under 25° the effectiveness of the forested area increases, mainly due to the losses of kinetic energy.

Technical recommendations should be divided first according to the main segments of which the target stand is composed of:

- release zone: where the release of rocky material take place,
- transit zone: intermediate segment where the rock increase its speed or the first interactions with the forest stand make it lose energy,
- runout or deposit zone: area where the rock has lost the total amount of its kinetic energy due to interactions with the forest stand or due to changes in the local topography. Nevertheless, if after a deposit area there is an abrupt increase of slope a deposite zone can be considered a potential release area.



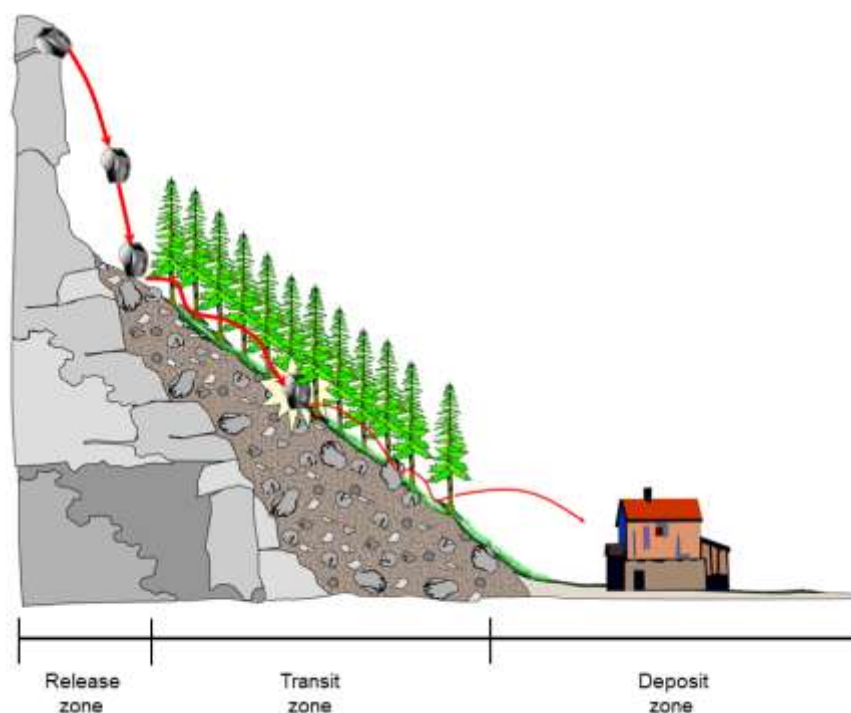
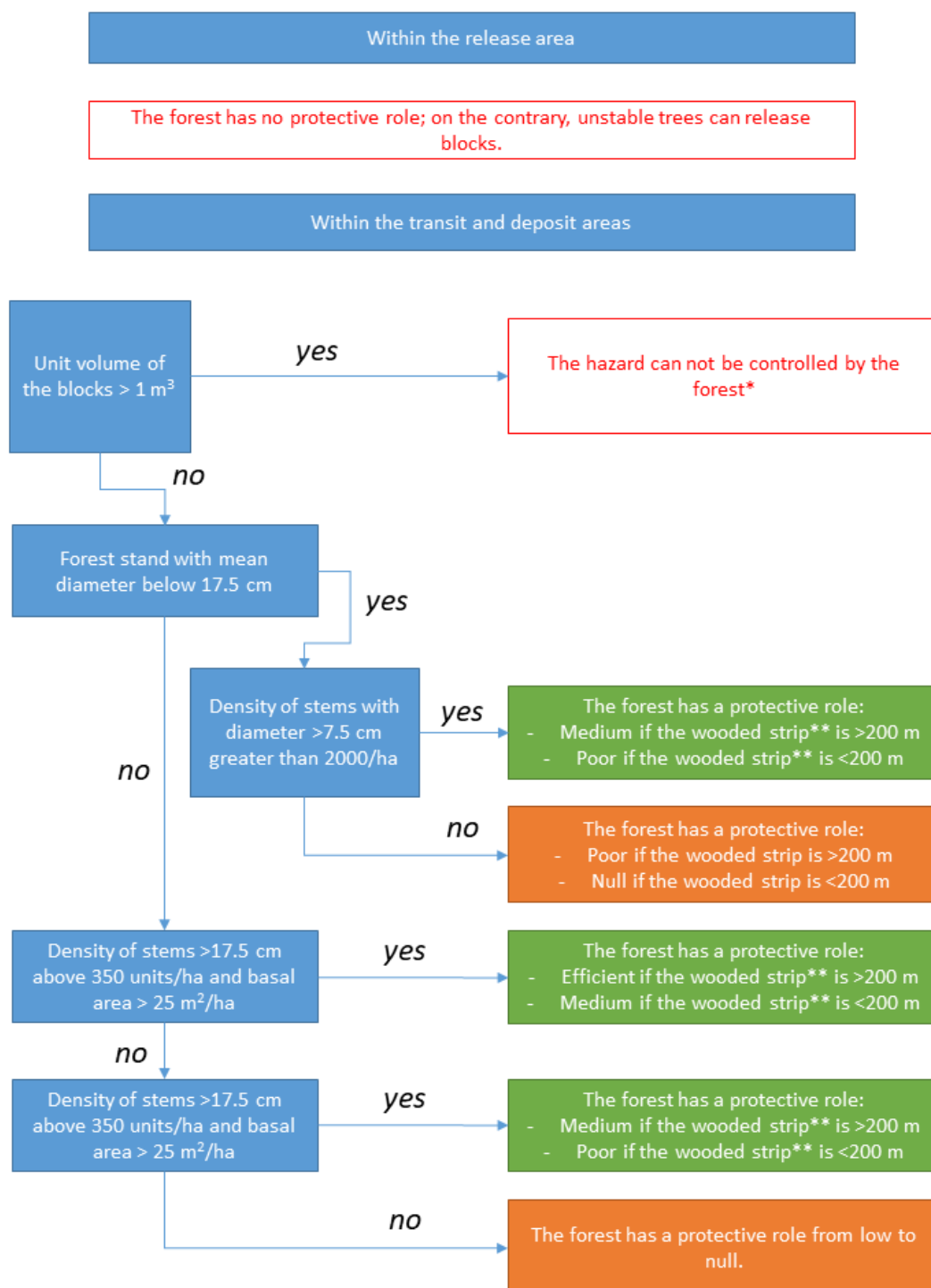


Figure 8: General scheme of the main zones in which a rockfall event can be divided (from Berger et al., 2013. Mod.).

Once the mentioned sections have been identified on the ground, a preliminary assessment of the main aspects related to the forested component can be carried out directly in the field using the following flowchart:

Diagnosis to be performed at the stand scale



*The maintenance of the forest is beneficial even when it cannot, on its own, provide effective protection.

**Planimetric length of the wooded strip in the direction of the slope.

Note: this diagnosis is a deliberately rough approach. Indeed, the multiplicity of parameters (size, shape and nature of the blocks, slope, entrance distance, structure and nature of the stand) the expertise of the control of falls of blocks particularly complex. For a precise determination of the role of the forest, an online tool is available on www.rockfor.net.

The release zone is a delicate zone for what concerns the forest component. In this area forest usually plays a limited role, which could have both positive and negative implications. Trees could have a positive influence in preventing the start of the rocks by holding them with their roots, but at the same time roots themselves can speed up the process of weathering (organic acid from roots and coniferous litter can corrode the rocks) and cracking (increasing frost wedging). Furthermore, when a tree that was holding rocks to the ground is swaying due to wind (e.g. tall tree) or even uprooting because of windthrow, rocks can be released. However, it should be promoted as much as possible the presence of trees in proximity of the zone of origin in order to limit the distance between the forest margin. In only 40 m without obstacles, rocks can reach their maximum speed and therefore the maximum kinetic energy (Frehener et al., 2005).

As a general suggestion, unstable trees should be removed when possible both on top of cliffs and at their bottom. If in the former case they can help the release of the rocks beneath, when they are located at the base of the cliff, they can re-release formerly blocked rocks. Furthermore, in order to contrast the very high energy with which rocks are present in such areas, it is suggested to have high values of basal area and low slenderness coefficient. This can be reached through appropriately timed thinnings, favouring the secondary growth of trees. Where possible, a preference towards a higher mix with broadleaves should be made, due to their average higher resistance (comparing to conifers with the same diameter) and resilience.

Management of gaps within the forest cover, natural ones or derived from harvesting operations, should be made. If gaps need to be created for regenerating the stand, the openings should be shorter than 20 and 40 metres along the slope direction for coppices and high stands, respectively (Frehener et al., 2005). Higher values indeed can allow the rock to recover its full kinetic energy making inefficient any previous impact.

In the case of protection forests that have protective role against multiple hazards, such as avalanches or rockfall events (typical situation in the montane and subalpine zones of the Alps), the prevalent one has to be tackled. Harvesting operations, indeed, should leave high stumps (appr. 1.30 m height) where snowpack has higher chances of sliding while, in the case of rockfall, removing stumps to the ground level could avoid the trampoline effect. Standard stumps can indeed alter the rolling process, enhancing the height of rebounding and increasing the energy of the rock itself. In rockfall sites, the release of high stumps can be allowed for providing anchors for felled trees in order to form barriers. These eco-engineering structures can act as an efficient barrier when laid down with an oblique angle but they should be considered as a temporary measure since woody material will decay.



Forest stands located in the transit and deposit zones can provide a significant mitigating effect against rockfall, since trees can act as energy-dissipating barriers. For this reason, the length of the forested area should be increased, especially in the situations where it does not reach the threshold of 250 m on the slope (200 m planimetric). The efficiency of energy reduction by a tree is strongly related to the size of the stem and to the size of the rock. Mean size and density of the trees should be evaluated according to the main characteristics of the typical event and to the species characteristics. The effective minimum diameters might help in assessing the protective efficiency of the current trees on the stand, providing further information on the target average size to reach. The tree density has always to be considered, since the wellknown relationship between tree density and average size. Furthermore stem density has to be considered in specific cases like in the coppices (see Chapter 3.1.1). In Table 2, the ranges of effective minimum diameter values can be found, along with the average rock volume against which they are effective.

Mixed stands should be generally always preferred, and if broadleaved species are present or potentially suitable for the site, leaving to this category more than the 30 % of the biggest trees is highly recommended.

In the transit zone, the basal area of trees with a DBH ≥ 15 cm is required to be ≥ 25 m²/ha, while within the runout zone is required to be ≥ 20 m²/ha. Nevertheless, in all cases the stem density for trees with diameter of ≥ 20 cm should be ≥ 350 stems/ha. In order to obtain a target profile of a protection forests of interest, it is strongly recommended to refer to the online tool RockforNET (www.ecorisq.org/rockfor-net-en).

Finally, in the case of corridors, a band of 25 m on either side of a corridor should be left, promoting trees with low values for slenderness coefficient (conifer stands: $H/D \leq 65$, broadleaves stands: $H/D \leq 80$).



Table 1: Silvicultural recommendations for rockfall sustainable mitigation by forest stands
(from Berger et al., 2013; mod.).

	Recommendations	Thresholds
Release zone	Remove unstable trees (leverage effect due to the wind) at the top of cliffs or outcrops and in the release area.	Coefficient of stability value (Height/Diameter at breast height = H/D) Coniferous: $H/D \leq 65$ Broadleaves: $H/D \leq 80$
	Maintain a high basal area compatible with the sustainability of the stand at the foot of the release area.	
	Whenever possible, limit the distance between the source area and the downslope stands.	
	Promote deciduous trees which are more resistant than conifers with equivalent diameter. Maintain more than 30% of deciduous trees among the largest trees. Depending on the ecological conditions, a certain amount of conifers are need for the stability of stands.	
	Harvest trees leaving stumps with a minimum height of 1.30 m, in case of prevailing snow hazard or need to anchor lying logs or, if rockfall can occur, completely remove stumps to ground-level (or screed in order to avoid a trampoline effect).	
	Fell/cut trees at an oblique angle to the slope leaving felled trees on the ground in a position that they cannot be easily moved.	
	If possible, increase the planimetric length of the wooded strip.	Recommended horizontal length of the wooden strip = 200 m
	Limit the size of gaps	Length of gap (measured on the slope) along the line of the steepest slope (H = average height of trees) High forest < 40 m Coppice < 20 m In all cases, recommended value: $L \leq 1.3 H$ with a wooded strip below the gap $> 2 H$ (recommended 4 H)
	Promote deciduous trees which are more resistant than conifers with equivalent diameter. Maintain more than 30% of	
Transit and runoff zones		



deciduous trees among the largest trees. Depending on the ecological conditions, a certain amount of conifers are needed for the stability of stands.	
Basal area and stand densities should be assessed through the whole slope length. The online tool RockforNET can serve as a support (www.ecorisq.org/rockfor-net-en)	In the <u>transit zone</u> : the basal area of trees with a diameter of ≥ 15 cm is required to be ≥ 25 m ² /ha.
	In the <u>runout zone</u> : the basal area of trees with a diameter of ≥ 15 cm is required to be ≥ 20 m ² /ha.
Maintain an adapted stem density for the efficient trees. Maintain a high density in a band of 25 m on either side of a corridor	In all cases the stem density for trees with diameter of ≥ 20 cm is required to be ≥ 350 stems/ha
Remove unstable trees along corridors	Values of the coefficient of stability (Height/Diameter at Breast Height = H/D) Coniferous: $H/D \leq 65$ Broadleaves: $H/D \leq 80$
Remove trees that pose a threat to infrastructures	

Table 2: Effective Minimum Diameter ranges according to the average rock volume (from Frehner et al., 2005).

Rock volume (m ³)	Rock diameter (cm)	Assumed effective minimum diameter
Up to 0.05 m ³	Up to about 40 cm	Up to 20 cm dbh
0.05 m ³ up to 0.20 m ³	About 40 cm to 60 cm	20-35 cm dbh
0.20 m ³ up to 5.0 m ³	Over about 60 cm	Over 35 cm dbh



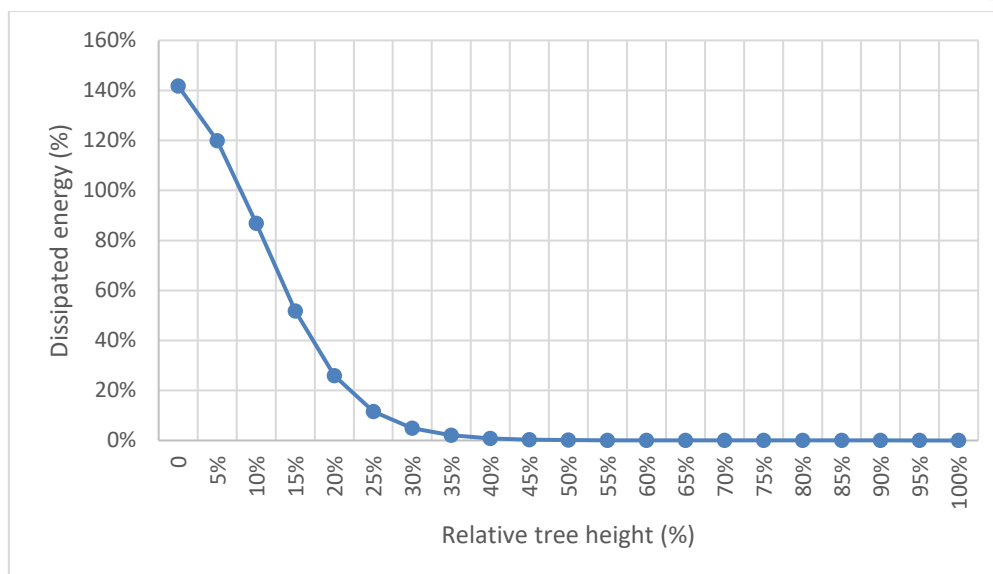


Figure 9: Percentage of maximal energy dissipated by a tree with a DBH of 20 cm and according to the ratio between the height of the impact and total tree height.

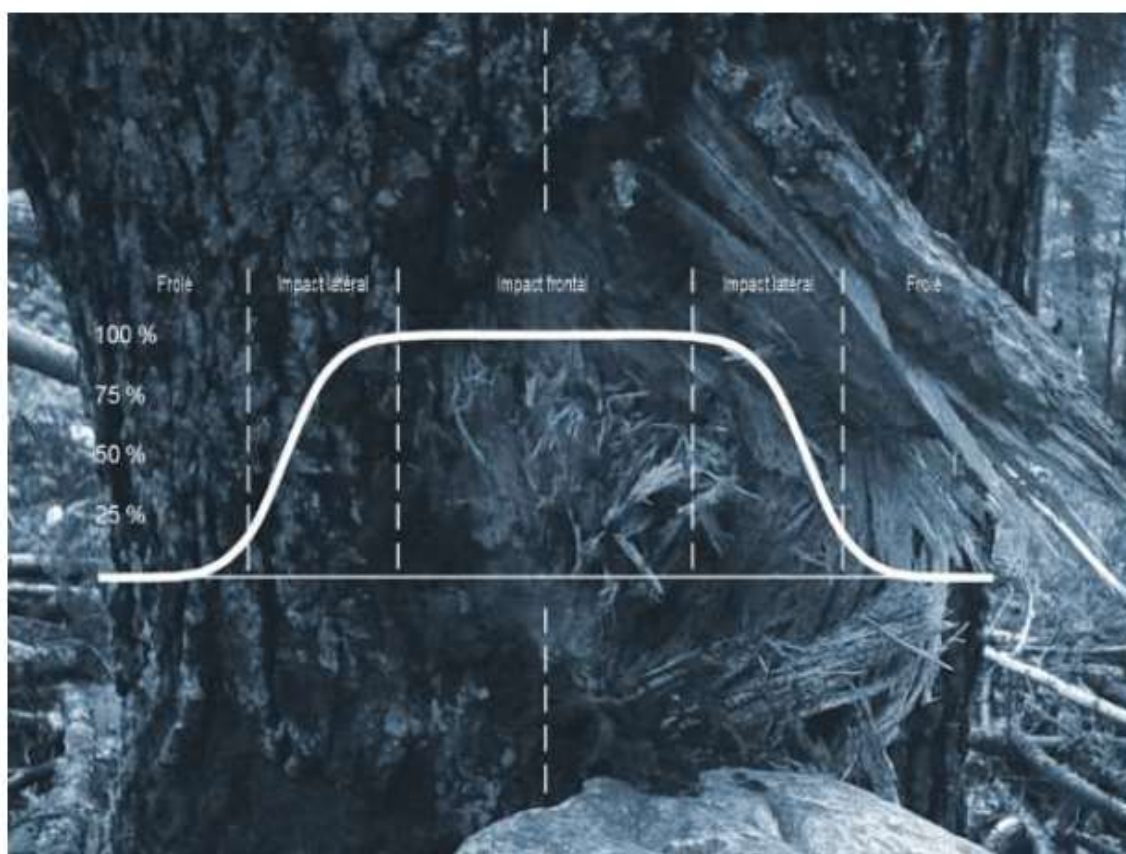


Figure 10: Amount of dissipated energy according to the different hit zone (lateral or frontal) on a tree stem.

3.1.1 Coppices

A particular case is represented by the management of coppice stands, either made up of shrubs or tree species. Plants with polycormic behaviour act as an efficient barrier against small rocks (below 20 cm in diameter), usually connected to frequent events on steep slopes and shallow soil. A density of 8000 stems/ha is considered a viable threshold for young and dense stands against this rock size (Janke et al., 2009), or volumes below 0.25 m³ (Omura and Marumo 1988, Cattiau et al. 1995). In addition, stools with more shoots can be assimilated to single individuals if they reach a minimum target diameter. For bigger rock sizes (> 0.5 m³), indeed, the basal area and dbh are more important than stem density (Ratke et al., 2014). Rocks up to 40 cm in diameter can be stopped by individuals with an effective minimum diameter between 12.5 and 20 cm. The same effect is assumed for a stool with four shoots of 6 cm. Older stools are thought to resist till rock volumes equal to 1 m³ thanks to an average thicker bark (Buckley et al., 2018). Even though overaging seems not to affect the protection function of old coppices (i.e. < 60 years), the stand tends towards a progressive loss of stools (Ratke et al., 2014).

In general, a heterogeneous dbh distribution is usually beneficial for forests with protection function and, in this case, this can be achieved through a management such as coppice with standards. Thanks to the retention of high number of standards, indeed, not only the dbh differentiation is guaranteed through space but it also could provide a partial continuous coverage through time.





Figure 11: Blocking effect of a healthy stool (Cevo, Italy).

3.1.2 Species

The resistance of trees and thus their capacity of dissipating the energy during the impact, with rocks strongly depends on the technological characteristics of the wood and not only on the size. Each species shows different resistance, with broadleaved species characterized generally by higher values (Figure 12). Indeed often conifer are referred as softwood and broadleaved as hardwood (with some exceptions). A simplified schematisation of resistance strengths for the most common Alpine species is reported in Table 3. Since trees are biological elements and their growth is affected by several environmental factors, the variability of their stems resistance is high, and is also due to the:

- Fibre inclination: increasing the angle between fibres and the vertical axis decreases resistance;
- Density: resistance increases with wood density values;
- Rings and wood defects: ring width influences wood density. Knots and cracks strongly decrease resistance to the dynamic hit.



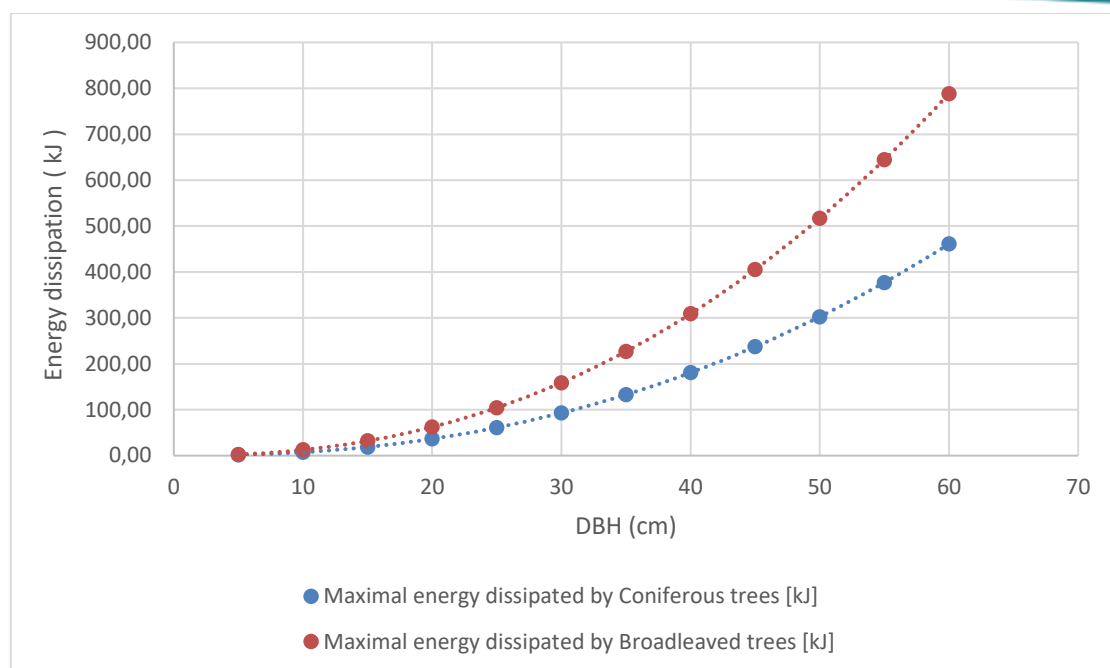


Figure 12: Maximum energy dissipation of conifers and broadleaves species (in kJ) by equal DBH ranges..

Table 3: Wood resistance according by species and taxonomic group, in decreasing order (data for broadleaves from ??? and for conifer from Giordano???).

	Species	MOR (MPa)	Resistance
Broadleaves	<i>Robinia pseudoacacia</i>	-	very high
	<i>Sorbus aucuparia</i>	-	high
	<i>Quercus petraea</i> , <i>Q. pubescens</i> , <i>Q. robur</i>	59	medium -high
	<i>Fagus sylvatica</i>	65	medium -high
	<i>Fraxinus excelsior</i> , <i>F. ornus</i>	66	high
	<i>Laburnum anagyroides</i>	-	high
	<i>Acer campestre</i> , <i>A. pseudoplatanus</i>	66	medium
	<i>Betulla pendula</i>	-	medium
	<i>Carpinus betulus</i>	66	medium
	<i>Ostrya carpinifolia</i>	-	medium
	<i>Castanea sativa</i>	52	low- medium
	<i>Alnus incana</i>	-	low- medium
	<i>Alnus glutinosa</i>	-	low
	<i>Populus alba</i> , <i>P. nigra</i> , <i>P. tremula</i>	-	low
	<i>Salix</i> ssp.	-	low
	<i>Tilia</i> ssp.	54	low
Conifers	<i>Larix decidua</i>	53	medium -high
	<i>Abies alba</i>	43	medium
	<i>Picea abies</i>	39	medium
	<i>Pinus cembra</i> , <i>P. sylvestris</i>	41	medium
	<i>Pinus montana</i> , <i>P. uncinata</i>	-	low



Figure 13: Chestnut stem neatly broken by the passage of a big rock (Cervo, Italy).

3.2 Protective effects of deadwood

The importance of deadwood presence in forest stands has been recognized in the last decades, mainly for the provision of habitat, carbon stocking, and regeneration microsites. Deadwood, both lying and standing indeed can also play an important role in protection forests against rockfall. This material can act in different ways for the protection against rockfall events, increasing the roughness of the surface and resulting in an obstacle to the falling rocks, potentially stopping them or reducing their energy. When present as snags or really tall stumps (higher than 1.3 m), they are comparable to standing trees as long as the wood is still sound but of course the resistance will decrease according to the decay processes that are quite site and species specific. When stumps are short, not levelled with the terrain they can easily promote rebounding. Downed logs help in diverging the straight fall of a rock and hence prolonging its path within the forest increasing the chances of further hits. For this reason, when lying deadwood derive from active management, the felling direction should be between 45°-70° less than the steepest slope direction (slope aspect). Current research, indeed, has shown that the felled trees have a significant effect on the energy loss (30% on average) and on the fall direction of the rock, diverging from straight runs and potentially increasing the hit chances.

Finally, the choice of the species to use results important in consideration of the durability through time. In only two years, indeed, European beech (*Fagus sylvatica* L.) and silver birch (*Betula pendula* Roth.) showed a significantly lower durability with > 20% wood degradation than Norway spruce or silver fir (Stokes 2002).



Figure 14: Single-frame sequence of a log blocking a rolling stone (photo: IRSTEA).

3.2.1 Protection structures made of felled trees

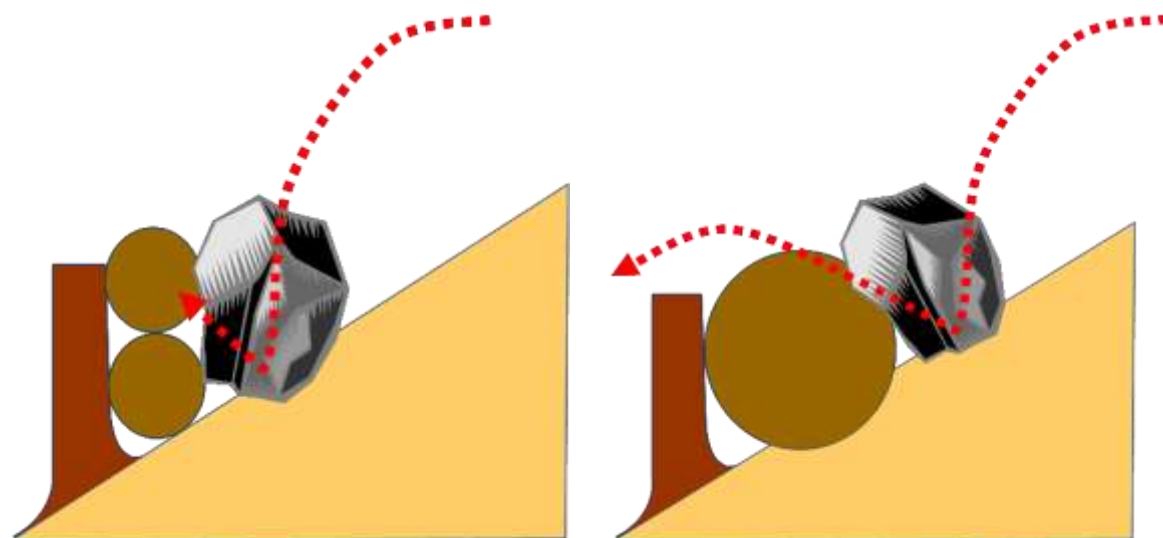
When in a forest stand the deadwood is not naturally present, by adopting an active management we can make it available. In all the situations in which we need to enhance the protection effect of the stand against rockfall hazard, we can achieve this goal through the creation of artificial structures by using biological material (eco-engineering structures). For what concerns their construction and use, some recommendations should be followed:

- It is preferable to make devices anchored at one end only. Although felled trees must be anchored to stumps and/or standing trees, one of the two anchorage points must be of the "brake" type, i.e. a dynamic anchorage that allows the device to move under the effect of an impact, thus promoting energy dissipation.
- Devices consisting of stacked logs are to be preferred in order to counteract the faster decomposition effect of the log in contact with the ground and to optimize the interception of the projectiles. The stacking of logs to create so-called "scissor-type" devices should also be favored because it promotes energy dissipation.

- Given the kinematics of wood decomposition, a structure made up of a log on the ground has a high loss of mechanical capacity during the first 10 years (between 50% and 90% depending on the species used) and a total loss of mechanical strength after 20 years. The maximum duration of effectiveness of a log in direct contact with the ground is therefore 10 years. It is recommended to develop an implementation strategy based on a ten-year implementation schedule.
- As hardwoods decompose on average faster than softwoods (on average, they decompose twice as fast), it is recommended that preference should be given to the use of resinous species when building structures with felled trees.
- The speed of decomposition of logs is higher than the stumps one, which is itself twice as fast as that of the root system. The weak point of a biological protection structure consisting of a log anchored to a stump is therefore the log.
- The loss of the mechanical properties of a log has a faster kinematics than the one of the physico-chemical properties. It is therefore advisable to pay close attention to the scope of visual observations to estimate the loss of mechanical strength of a slash.
- Structures are more effective in a wooded context than on bare ground because of the combined effect of trees and structures: the presence of trees reduces the propagation height and the energy of the boulders, which makes the structures more effective.
- It is preferable to locate the structures as close as possible to the starting point of the rocks.
- It is not necessary to build a very large number of structures (typically more than 3) unless the productivity of the cliff is very high (higher probability of destruction of the structures).
- To build a structure of a given height, it is preferable to build stacked tree structures because it is not the relative size between the blocks and the trees that conditions the efficiency but the creation of a vertical obstacle in which the blocks are preferentially trapped (favored energy dissipation) (Figure 15a).
- In order to limit the negative effect (springboard effect) of the presence of low stumps, it is necessary to give preference to high stumps of at least 1.30m high on the upslope side and if necessary beveled from upslope to downslope (Figure 15b).
- Given the positive role of felled trees, it is appropriate to leave trees on the ground even in logged stands in order to compensate for the negative effect of the stumps.



a)



b)

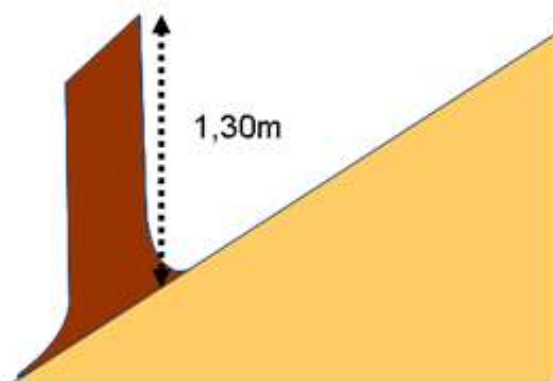


Figure 15: a) A stacked log structure is more efficient than a single log structure with an equivalent diameter.
b) Stump bevelled from upslope to downslope in the line of greatest slope.



Figure 16: Example of a structure made by stacking logs.



4 PROTECTION SERVICE PROVISION IN A CHANGING WORLD

It is foreseen that in the next future climate change will alter directly and indirectly forest ecosystems, particularly in mountainous areas, as well as the disturbances regimes that may affect those forests (Seidl et al., 2017; Seidl and Rammer 2017; Thom et al., 2017).

Climate change will entail an increase of mean annual temperature and a mutation of precipitation patterns, therefore it is expected a mid- and long-term modification of some forest stand parameters crucial for the provision of the protective function, such as trees growth rate, forest cover extent and trees species composition, favouring the species more adapt to the new environmental conditions (Albrich et al., 2018).

Disturbance regimes, as well, are expected to be deeply affected by climate change in many parts of the world (Dale et al., 2001; Seidl et al., 2017) and forests will possibly face new disturbance regimes, for which will not be prepared, stemming from the combined modification of biotic and abiotic disturbance patterns (Temperli et al. 2013).

In fact, forests structures and species compositions are now in a steady state with usual disturbance regimes, intended as specific intensity and return interval of the disturbance; forest ecosystems are able to persist after or resist to usual disturbances, but if the regime will vary, so will probably do the species compositions and the forests structures. In this view, discrete severe events, such as natural disturbances, can affect the forests more than a gradual change of the temperature (Lindner et al., 2014) and more suddenly than climate change which, acting on trees stress and stand decline, may take years to bring trees to death.

Management of protection forests must always heed two main issues: species fitness and non-permanence of the forest (Dyderski et al., 2018). Regarding the latest, a severe natural disturbance can partially or totally remove the trees cover of a protection forest that will have after a changed protection performance based on structure and species composition of the remaining stands.

In case of insects outbreaks or wildfires, dead standing trees will remain in the stands for a variable period of time, depending on trees size and species (Marzano et al., 2012), whereas, in case of windthrows, mostly uprooted trees and downed logs will cover the area. In addition, natural disturbances are usually connected, and an event of one kind can trigger a second, different one or amplify the intensity of it: for example, insects' outbreaks are usually promoted by windthrows or severe droughts, and in turn standing dead trees killed by pests and diseases can increase the fire hazard.

Considering all the aspects together, due to climate change mean air temperatures will rise and water will become less available to plants: if sudden, even small changes in environmental conditions can stress the trees and this can favour the outbreak of biotic agents (Bentz et al., 2010). The new environmental conditions will increase the general wildfire risk,



especially in the Alpine valleys that are already now dry and, most importantly, the increase in number of extreme, prolonged droughts will be pivotal in the probability of having large stand-replacing wildfires (Zumbrunnen et al., 2009; Eelkin et al., 2013). Eventually, wildfires will have effect on rockfall events, both directly, releasing rocks previously stopped by trees or heating the rock walls, and indirectly, removing the vegetation that used to mitigate the weathering and cracking processes.

The focus of forest management needs to be on the regeneration, the most vulnerable forest stage, because mature trees already have a robust and expanded root system by which are able to face environmental stress to a higher level than seedlings.

With regards to rockfalls, it is expected an increase in their occurrence caused by climate change (Berger et al., 2017) because, although being rockfall itself an unpredictable phenomenon, the triggering factors are significantly related to the weather. For example, rockfall events generally follow wide and rapid temperature variation, long and intense precipitation, freeze-thaw cycles that can frost-crack the rock and, in general, an increase number of rockfall events seems to follow years with anomalous weather (Berger et al., 2017).

In the view of the rockfall hazard, however, climate change will not only modify rocks release, but will also and more importantly affect the protection forests designated to mitigate the related risk; therefore, forest management will have the duty to ensure resistance and resilience of the protection forest stands also in a condition of changed climate by identification and mitigation of the potential threats to the forest (Lingua et al. 2020).

An expected major change in Alpine forests will be a change in species composition. Even if many forests are still similar to their natural condition, many mid-altitude forest stands (1000-1500 m.a.s.l.) were originated in the last century due to massive reforestation projects, in which predominantly conifers (chiefly spruce) were used to quickly revegetate the slopes at risk of erosion –left barren after the World Wars – and to maximise timber production in these areas. These very homogeneous stands now show low ecological and mechanical stability, sometimes aggravated by lack of management (thinnings not performed).

A suggested management strategy for Alpine forests would be the mapping of forest types, in order to have precious information on species composition, and to favour mixed stands, with the species mixtures of broadleaves and conifers varying according to the altitude and to the forecasted elevation range shift of trees species.

Some trees species that should be favoured in the future in the Alpine area are silver fir (*Abies alba*), European beech (*Fagus sylvatica*) and European oak (*Quercus robur*): the first has been found unexpectedly also in forest sites in Central Austrian Alpine forests, the second has been encountered in a way wider areal than expected in the mountain belt and the latest can vegetate already, under the current climate, up to 1000-1200 m.a.s.l. in some regions.



A brief mention should be made on the expansion and colonisation of alien species, like *Ailanthus altissima*, that are altering or replacing forest communities at the lower end of the mountainous belt.

In the case of *Ailanthus altissima*, this species has started to colonise steep slopes in the Southern Alps forming monospecific forests; from a rockfall hazard point of view, these formations may even increase the rockfall hazard due to the poor mechanical quality of *Ailanthus* wood, often susceptible of heart rot, and consequently inadequate in dissipating rocks kinetic energy. Notwithstanding, a recent study (Moos et al., 2019) pointed out that the scarce performance of this species is highly correlated to the structure of the forest, with young, newly-set forests of many trees and small mean diameter providing less mitigation than other species to rockfall hazard, but as soon as the mean diameter increases, the species behaves as the other ones considered.

4.1 **Economical evaluation of protection forests**

The evaluation of Ecosystem Services is becoming more and more used in the view of an integrated approach to forest economy. The service provided by protection forests more than others deserves a proper estimation to justify management strategies sometimes underestimated by administrators or to help land managers realise a fairer value of forests often located on difficult sites.

Among the available tools for the evaluation of the protection service value at local scale, we can find the ASFORSEE model. This model has been developed in the RocktheAlps project, and calibrated on the test sites provided by the project partners, located all over the Alpine space. Allowing the choice between two main evaluation methods, replacement cost and avoided damage approaches, the model leads to the estimation of different monetary value options according to the management applied to the target stand.

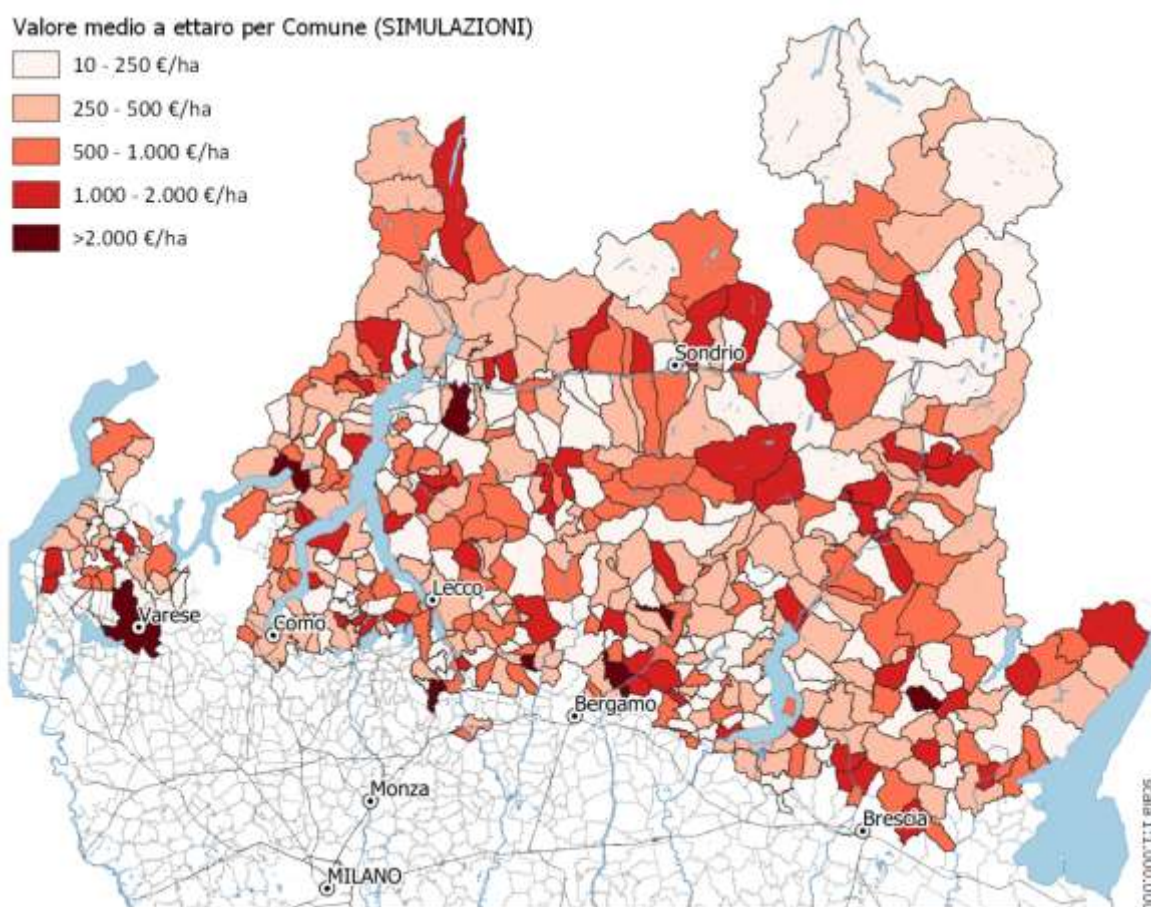
Further information can be found in the Appendix 1.



Ecosystem Services evaluation: a regional scale perspective

A first experience for the assessment of the economical evaluation of Ecosystem Services at regional scale was carried out by ERSAP (Regional Service for Agriculture and Forestry) for the whole territory of Lombardy region. The methodology followed the estimation principle known as “replacement cost method”, adapting and updating previous work done by Notaro and Paletto (2012), and making use of the map of protection forests developed by the department of Applied Geology of the Milano Bicocca University. The value of protection forests has been approximately quantified in 39 Mln € per year and average unitary values between 265 and 350 €/ha.

Further details can be found in the document titled “Valore economico del servizio ecosistemico di protezione dalla caduta massi svolto dalle foreste: metodologia ed esercizio di stima a scala regionale per la Lombardia - Documento di sintesi” [Italian only].



5 A MAP OF PROTECTION FORESTS AT THE ALPINE SPACE SCALE

Among the results of the project, the main outputs are the first maps of protection forests and their abundance according to the main reference areas for the Alpine range: the Alpine Space and the Alpine Convention. As it is possible to see in detail in the Table 4, protection forests cover the 14% of the forested territory of the Alpine Space area and almost 21% of the Alpine Convention one.

Table 4: Summary of the protection forest abundance at state level according to the Alpine Space and Alpine Convention areas.

Alpine Space area					
Country	Proportion of release area 28° - 42°	Forest area [km ²]	Proportion of protection forest		
			28° - 42°	≥ 42°	Total
Austria	14,90%	37280 (44,4%)	8,60%	3,70%	12,30%
Germany	2,60%	16410 (35,6%)	2,60%	0,70%	3,30%
France	8,60%	42765 (42,2%)	6,00%	2,60%	8,60%
Italy	16,80%	35165 (36,2%)	15,70%	9,00%	24,70%
Liechtenstein	25,00%	75 (46,9%)	16,00%	11,70%	27,80%
Slovenia	7,70%	11810 (58,3%)	6,50%	1,90%	8,40%
Switzerland	0,193	12650 (30,6%)	13,60%	12,50%	26,10%
Total	12,40%	156155 (40,0%)	9,10%	4,90%	14,00%

Alpine Convention area					
Country	Proportion of release area 28° - 42°	Forest area [km ²]	Proportion of protection forest		
			28° - 42°	≥ 42°	Total
Austria	22,90%	28830 (52,8%)	10,90%	4,70%	15,60%
Germany	10,90%	4655 (41,7%)	4,80%	2,20%	7,10%
France	21,30%	19365 (47,5%)	10,60%	5,40%	16,00%
Italy	31,30%	28460 (54,7%)	18,20%	11,00%	29,20%
Liechtenstein	26,70%	75 (46,9%)	16,00%	11,70%	27,80%
Slovenia	23,20%	4630 (68,4%)	11,70%	4,20%	15,90%
Switzerland	31,60%	7610 (30,2%)	20,20%	20,40%	40,50%
Total	25,30%	93625 (49,1%)	13,50%	7,90%	21,50%

On the total area of the Alpine Space (390 230 km²), the forest cover represent 40% of the area (156 155 km²). 14% of the forest cover has a protection function against rockfall. 9.1% are detected considering a slope threshold of 42° and 4.9% are detected considering a slope threshold of 28°. The maps correctly detected the majority of historical events, 90% of the 3685



real rockfall events were located inside the modeled rockfall propagation area (Figure 4). Considering release areas in slopes $\geq 42^\circ$, 65% of the real events intersected the propagation areas, and 25% were located in the propagation areas from release areas in slopes in $28-42^\circ$. Only 10% of the real rockfall events did not intersect modelled rockfall propagation areas. Nonetheless, about half of them were located close to a propagation area, e.g. within a distance less or equal than the raster resolution of 25 m. Full maps and further details can be found in the “Download” section of the official website.

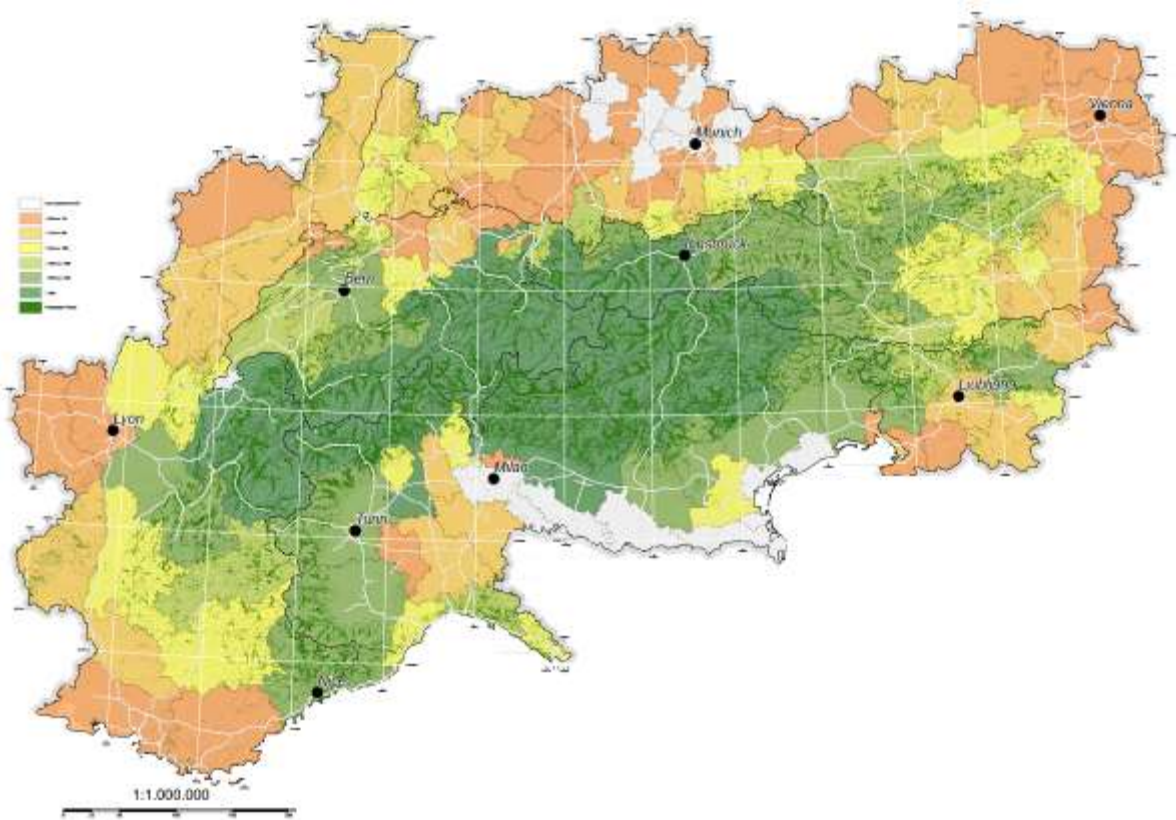


Figure 17: Mapping of protection forests at the NUTS 3 level.

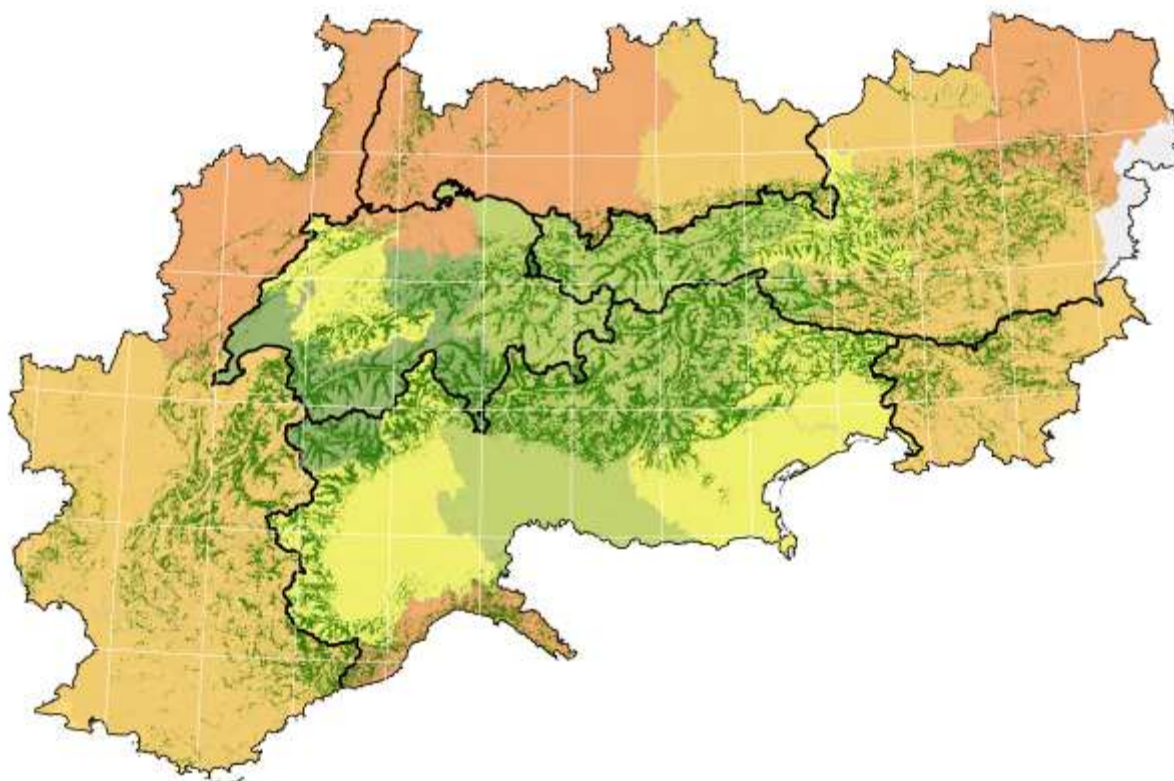


Figure 18: Mapping of protection forests at the NUTS 2 level.

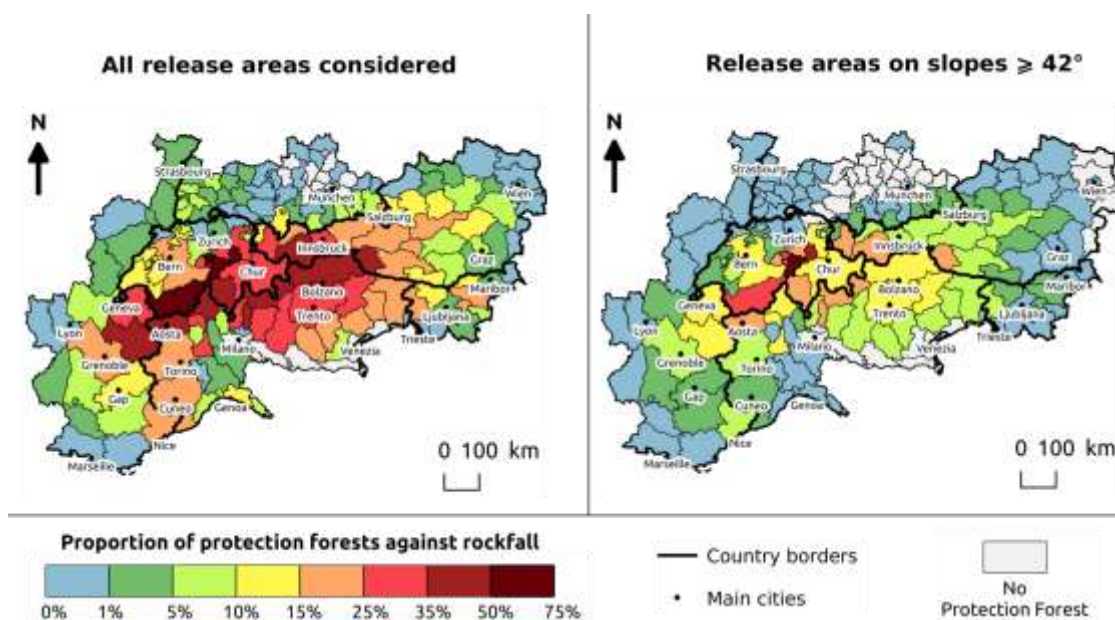


Figure 19: Maps of the proportion of protection forest against rockfalls according to the slope of the release area.

The RocktheAlps project was focused on the realization of the first harmonized map of forests with a protection function against rockfall hazard at the AS scale. The map produced in

this study was devoted to practitioners and stakeholders in order to identify hotspots and prioritize forest management interventions. This map is furthermore of great relevance for managers, local and regional administrations, and policy makers, providing for the first time sound data on this important ecosystem service provided by the Alpine forests. The maps and the results of the project are highly replicable and easily updatable since all the methodologies are based on the use of open source data that allows the reproducibility of the work and facilitates its updating according to changes in land use.



6 MAIN REFERENCES AND SUGGESTED READINGS

¹ <https://land.copernicus.eu/>

² <https://www.openstreetmap.org/copyright/en>

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7 APPENDIX 1

Appendix 1 is a collection of material that aims at deepening previously introduced topics or let the reader explore additional applications of what has been studied throughout the project.



7.1 The ASFORESEE model

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Considering the need to take simultaneously into account two alternative evaluation methods within the same model, the ASFORESEE structure has been developed in order to work in parallel for both. Nonetheless, some common aspects between the two are still present, as explained in the following paragraphs (Figure 20).

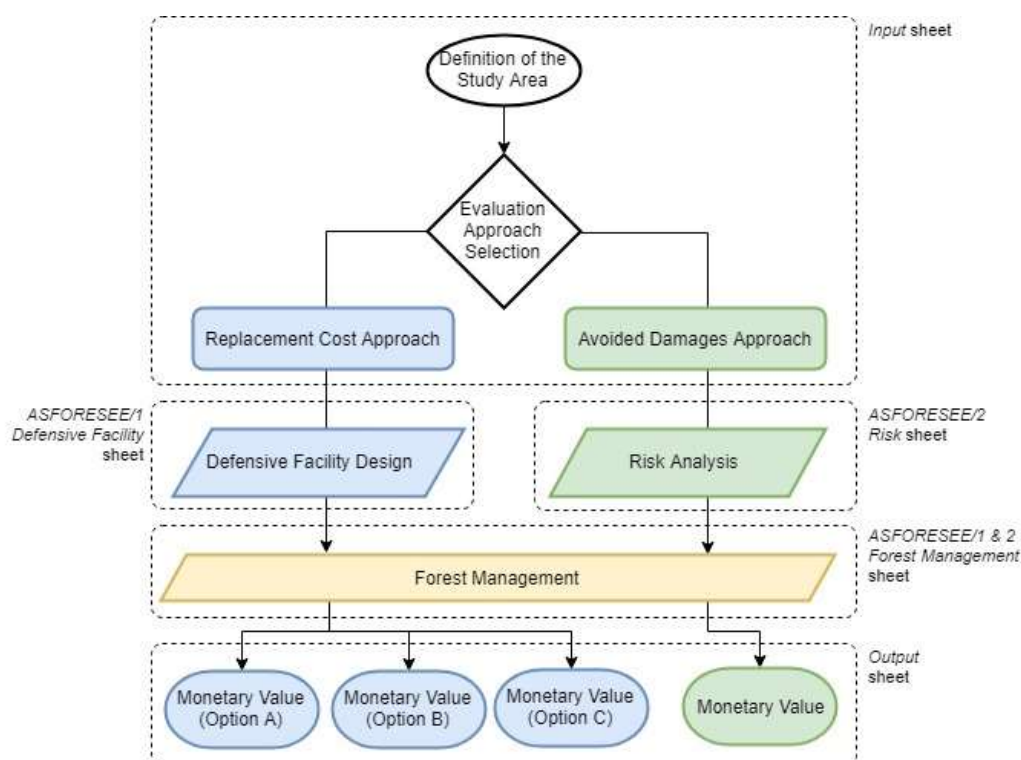


Figure 20: The framework of ASFORESEE; in blue the components dealing with the RC approach only, in green those dealing with the AD only, in yellow their common components; the dotted lines defines the content of each sheet of the Excel file constituting the mode.

The flow chart represented in Figure 20 depicts the framework underlying the ASFORESEE model. Once selected the study area, characterized by the presence of rockfall hazard, a forest and one or more exposed assets, the evaluation approach has to be selected. From this dichotomy, the model work in parallel, focusing on the specific methodological aspects that characterize the two methods. Finally, their result is represented by a monetary sum expressing the value of the protection environmental service (ES) that the forest provides against the rockfall risk. This structure can be recognised also in the internal organization of the model itself.

The first sheet of the Excel file contains the list of the different cell formats adopted throughout the model. For each of them the content that characterizes the cell is described in order to provide the user with a support in understanding the functioning of the model itself.

In the second sheet of the model the user can find an extensive list of Input needed to run the model. This sheet is generally organized in four main columns (A, B, C and D) respectively showing the type of data needed, its value, its unit of measure and its range of possible values. This sheet also presents the two available approaches, i.e. the RC (named ASFORESEE/1 in the file) and the AD (named ASFORESEE/2). ASFORESEE/1 is based on the RC approach, one of the most suitable methods to assess regulation and protective ES [13] and whose adoption in mountainous areas is well documented [9,14,15]. The approach states that the value of the protective function ensured by forests against rockfall is equal to the expenditures incurred to reproduce the same service with artificial means. For its application, several technical, economic and modelling inputs are needed. These data are listed in the cells of the “Input” sheet of the file. Among the other data, it is important to highlight one of the innovations of the model. Based on a “ES-inspired” approach, the model assesses both a “demand” side of this ES and a “supply” side provided by the protection forest stands. According to this approach, only if there is a need for this protection from rockfall by the society the ES provided by the forest occurs [16]. Therefore, in order to measure the value of this function, both demand and supply have to be assessed [17]. For the protection ES, an evaluation of the demand can be implemented, considering both technical and social factors [18] in order to define a “desired protection level” from the stakeholders, which can vary in relation to the importance of the good at risk [19]. In ASFORESEE, the demand for protection is assessed involving the stakeholders having specific roles in the area concerning the management and planning of forest, infrastructures and public safety. First, risk classes have been defined, following the categories set by the PAI (Hydrogeological Master Plan), then, the result is combined with the values obtained through a specific survey set to collect the stakeholders. The survey is composed by five questions on the topic of demand for protection, plus few other questions for statistical purposes only.

Instead, ASFORESEE/2 is based on the AD approach. This second evaluation method focuses on the object of this service, rather than on the subject providing the protection as happened in the previous approach. Therefore, the value of the ES will be estimated in relation to the value of the assets protected by the forest [20]. In order to link together the rockfall hazard, the forest and the assets, the AD approach operated by a series of subordinate probabilities inter-related one to the other [21]. As ASFORESEE/1, this

method is intended to be adopted at local level only, performing an evaluation of the service provided by one single forest stand.

It is worth to highlight that, since the two available approaches are strictly alternative, the user will follow a different path throughout the file in relation to the decision that was taken. Consequently, the economic results achieved with the two approaches cannot be compared, since based on a different conceptual basis. Based on the information presented previously, now the user should be able to select the most suitable approach in relation to the features of the study area and its aims.

The third sheet of the file is dedicated to the first approach only. Here, the defensive facility needed to estimate the value of the protection service offered by the forest is designed in a standardized way and evaluated in its building, maintenance and removal cost. In this sheet and in the following ones the user is not supposed to insert any additional information nor make any modification of the content of the cells.

A similar structure characterizes the “ASFORESEE 2 Risk” sheet of the model, where the rockfall risks are evaluated in relation to the assets located in the exposed area. This sheet, concerning the AD approach only, presents a results box in the first lines, and then the computations are listed in detail in the following lines. The result achieved in this sheet is constituted by an economic evaluation of the damages to the assets at risk avoided due to the presence of the protection forest.

The fifth sheet of the model is named “ASFORESEE/1&2 forest Management” and is the only sheet in common for both the evaluation approaches available. Here, the Stumpage Value, that is the economic balance of costs and revenues of the forest interventions to be performed in the stand, is computed. Similarly, to the previous ones, this sheet presents a result heading and then a list of computations needed to obtain this value. In this sheet, the role of forest management in mitigating the rockfall risk is investigated and assessed. Forest management constitutes the last element contributing to the protection value in relation to the silvicultural activities carried out in the stand. Silviculture in rockfall protection forests mainly consists in diversifying the stand structure by intervening regularly, every 10 to 15 years [22], to support the establishment of 40 cm or more diameter class and to develop an abundant regeneration. This approach aims to maintain, and possibly increase, the level of protection ensured by the forest stand while ensuring its resilience, stability and perpetuation. On the other hand, often these interventions result in negative stumpage values due to the high harvesting costs and the low productivity rates, often situated in steep areas [23,24]. ASFORESEE estimates the management expenditures with data that are usually included in the Forest Management Plan of the stand. Therefore, their use does not require any further data collection phase. The net present value of the forest management expenses has been computed summing up the discounted stumpage values of all the planned interventions.

Finally, in the last sheet of the model, its outputs are presented, providing a different economic value of the protection ES in relation to the selected approach. In the first lines, in fact, a reminder of the decision took by the user in the Input sheet is inserted in order to address the user toward the correct section of the sheet. Below this, we find five areas where the results are presented: four concerning the RC approach, and one for the AD approach. Particularly, the four sections dealing with the RC approach deploy the monetary evaluation into three alternative options. These options take in account all possible conditions the forest effectiveness and the stakeholders' needs can establish. In this first box it is verified if the forest has a relevant protective role for the case study. Then, the evaluation of the demand for protection of the stakeholders is compared with the values of the forest effectiveness. The answer to these two questions will determine the most suitable option to assess the value of the protection service, indicated to the user in the bottom line of the first box in blue. Finally, in the last section of the output sheet the user will find the economic evaluation of the forest protection service according to the AD approach. Here only one option is available, since the comparison between the supply and demand of this ES is replaced by the calculation of the value of the assets at risk. The results of this evaluation method consist in a monetary value as well, expressing the amount of damages the presence of the forest allows to avoid.

Once assigned the case study to one of the available options, the economic value of the protection forest against rockfall events is obtained. In this respect, it should be remembered how the protection value is not an exchange value, but rather the translation in economic terms of a service that can be obtained only through a virtuous management of the ecosystem generating it [25]. For both approaches, in order to improve the understanding of its measurement and widen its applicability, ASFORESEE expresses the result of the monetary evaluation in several alternative ways. Particularly, the protection ES can be presented as a total value, in € per stand or in € ha⁻¹, or as a yearly benefit, in € ha⁻¹ y⁻¹. Even if the last valuation form could lead to some misunderstanding, its adoption is widely spread [14, 26] and results are presented in the most suitable way to communicate directly with stakeholders, decision-makers and other non-scientific actors thanks to its immediacy and comprehensibility.

Further details regarding the functioning of the model and the format of the input data can be found in the report D.T4.3.1 titled “ASFORSEE general presentation”.

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7.2 TORRID - Toolbox for assessing the protective effect of forests against rOckfall and expressing the protective role in a Risk Reduction InDex

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7.2.1 Introduction and basic concepts

Mountain forests play an important role in the protection against rockfall events. Within the Interreg Alpine Space project RockTheAlps the focus is on how the protection effect can be quantified, allowing to establish a rockfall risk reduction (RRR) index for mountain forests. Based on multiple rockfall simulations on a virtual terrain, parameterized by real forest stand data, Dupire et al. (2016) presented three risk reduction indexes accounting for the protection effect of forests:

1. $BARI(x)$ is an indicator of frequency reduction of the rock-fall hazard as it directly gives the percentage of rocks stopped due to the presence of forest on x m along the maximum slope direction. It is defined as:

$$BARI(x) = 100 \left(1 - \frac{N_{forest}(x)}{N_{no-forest}(x)} \right) \quad \text{Eq. (1)}$$

2. $MIRI(x)$, the rockfall Maximum Intensity Reduction Index is related to the 95th percentile of the energy of all the passing rocks at distance x m along the maximum slope direction. It is defined as:

$$MIRI(x) = 100 \left(1 - \frac{E_{95forest}(x)}{E_{95no-forest}(x)} \right) \quad \text{Eq. (2)}$$

3. $ORPI(x)$, the third indicator integrates both the proportion of stopped rocks and the total energy reduction of rocks due to the presence of forest – defined as:

$$ORPI(x) = 100 \left(1 - \frac{E_{cumforest}(x)}{E_{cumno-forest}(x)} \right) \quad \text{Eq. (3)}$$

The risk reduction index as proposed by TORRID follows the concept of the indexes defined by Dupire et al. (2016). However, TORRID is intended to act on a broader scale (the whole Alpine Space) in combination with ROCK-EU a simple but effective rock fall simulation model based on the energy line approach. For this reason, the TORRID index is defined as.

$$TORRID(x) = 100 \left(1 - \frac{\alpha}{\beta} \right) \quad \text{Eq. (4)}$$

Here α refers to the energy angle or the lumped friction slope, resulting in a maximum runout length of a potential rock fall event without forest. For the same rock fall event the presence of forests along the profile might act as a simple barrier decreasing the energy



Example 1:

The back calculated energy angle of an observed rock fall event which passes a forest stand was estimated with $\beta = 28^\circ$. The energy angle for the same scenario not accounting for the forest is predicted with $\alpha = 20^\circ$. The risk reduction caused by the forest stand for the maximal observed runout distance is therefore:

$$100 \cdot \left(1 - \frac{20}{28}\right) = 28.6\%$$

In other words, the presented forest reduces the total energy by about 30%.

angle respectively lumped friction slope – denoted as β . The relation between α and β can again be expressed as a dimensionless index similar to the $ORPI(x)$ index - but solely by using an energy line approach to simulate rock falls (Figure 1). Here the distance x equals to the maximum runout when accounting for forest, e.g. when applying the energy angle β (Example 1).

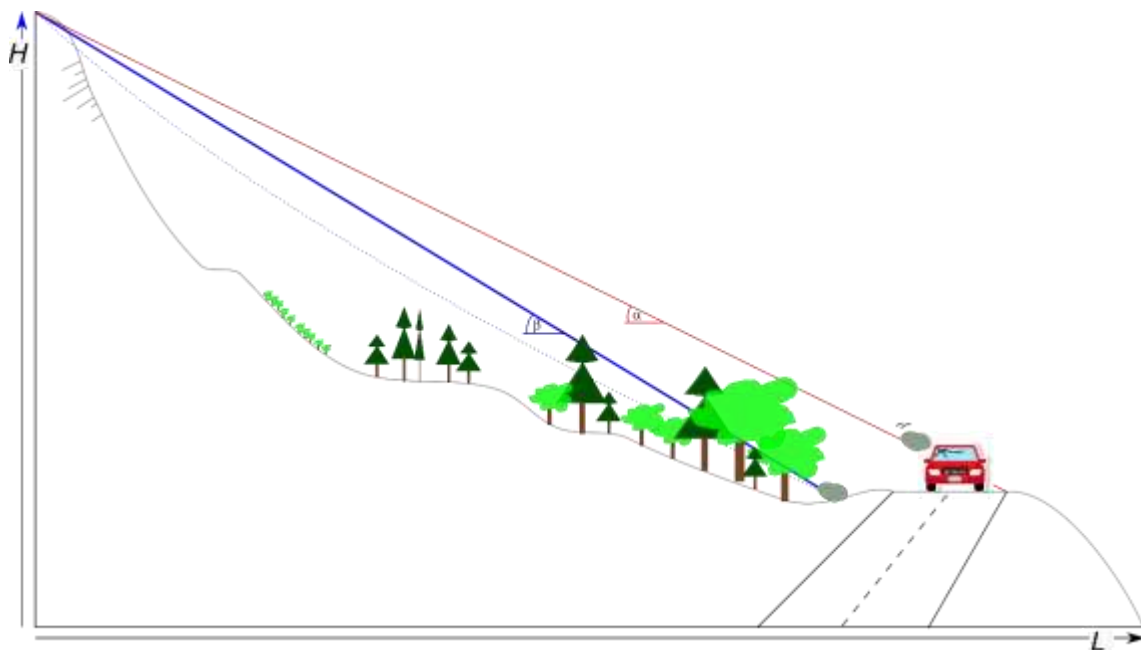


Figure 21: Concept of energy reduction of a rock fall event due to forest stands.

However, beside energy reduction also the frequency reduction of the rock fall hazard needs to be considered. For this reason, empirical based survival functions of the rocks for different forest sites are modeled. We hypothesize that different forest sites will have different survival curves of rocks along the rock-fall path (Figure 22) which can be grouped to get specific survival curves for a “specific” forest stand type.



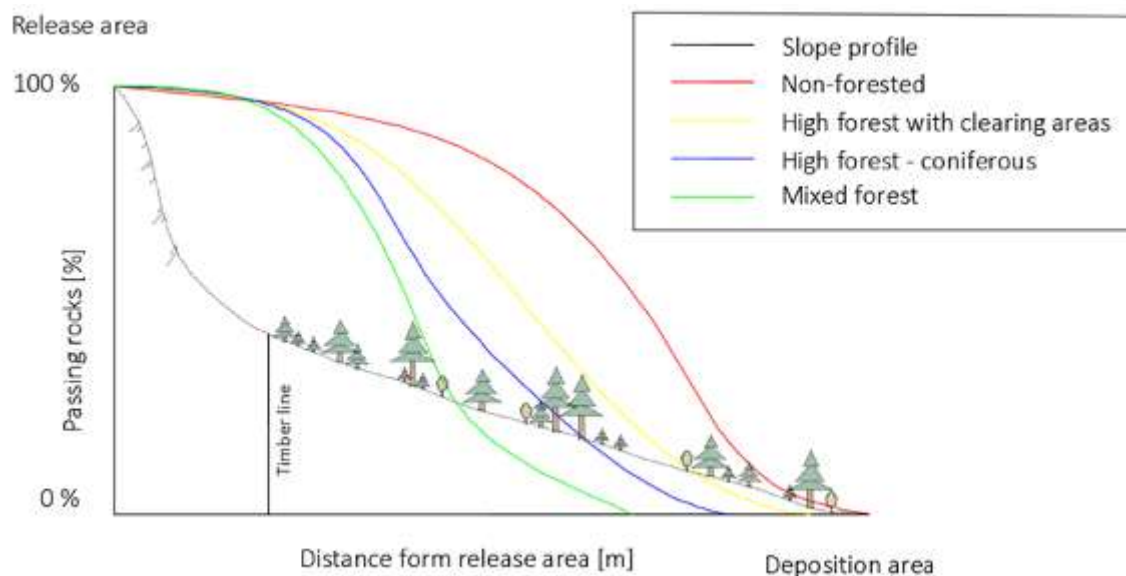


Figure 22: Schematic survival curves for rocks reaching a certain distance from the release area, grouped by different forest stands.

Normalizing those specific survival curves allows us to provide an adapted survival function for the actual forest stands along the considered rock-fall path (Figure 23).

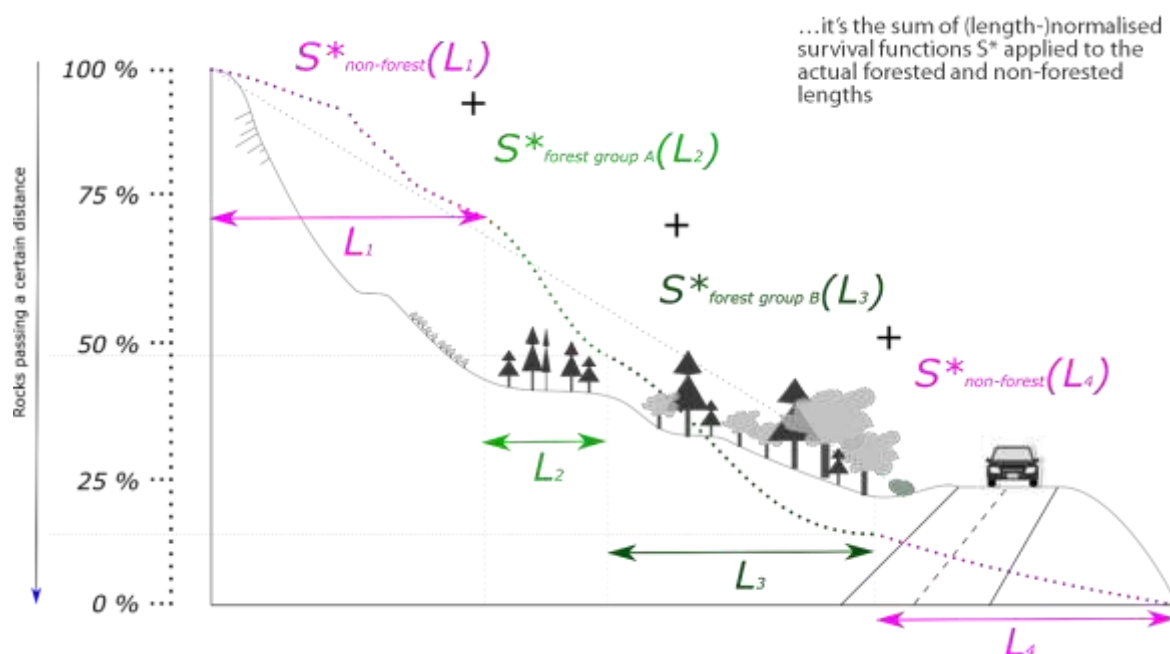


Figure 23: Example of an adapted survival function to the actual non-forest and two different forest stands based on a combination of length normalized specific survival curves.

Thus, the adaptive survival function acts as a probability function to predict the number of rocks reaching a certain distance from the release area. This can indirectly be used to estimate a specific distance at which on average a certain percentage of all rocks should be deposited (Example 2). We denote this specific distance with L_{ALARP} (ALARP = As Low As Reasonably Possible). L_{ALARP} provides the base to estimate β and subsequently allows the calculation of the TORRID risk reduction index for the user defined distance $x = L_{ALARP}$ (cp. Equation 4).

Example 2:

Based on an adaptive survival function for a given rock-fall path we can estimate the distance (L_{ALARP}) for which 90% off all rocks will most likely be deposited. Or, in other words, 10% of all rocks are expected to exceed this distance (Figure 18).

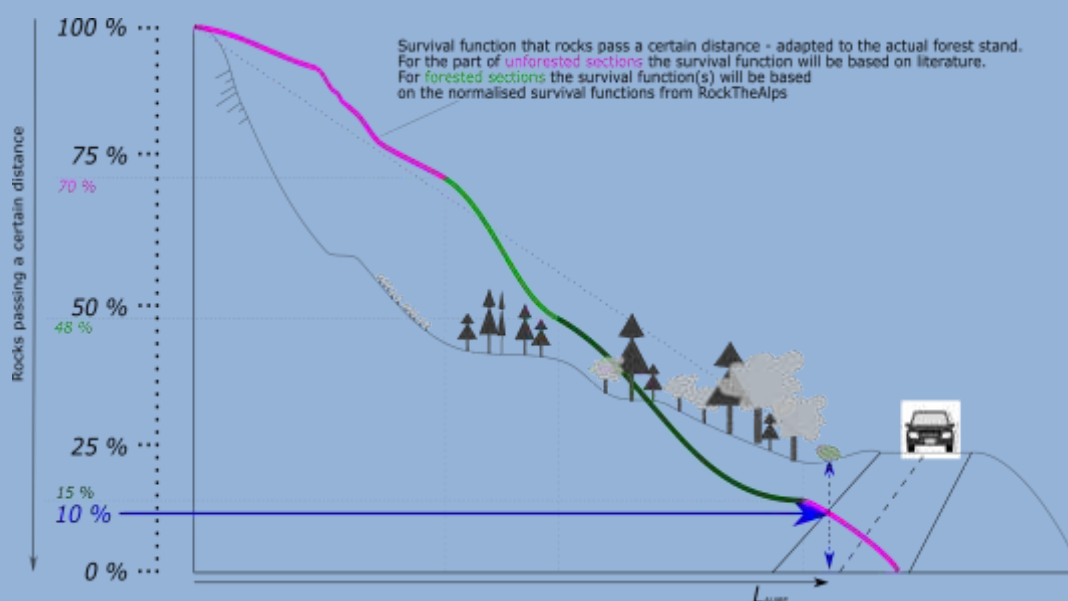


Figure 24: Adaptive survival function for a given rock path with two different forest stands.

7.2.2 Identify and harmonize the required parameters and thresholds for TORRID

A major contribution of the TORRID concept is based on the development of different specific survival curves for homogenous forest stands (Figure 7). These survival

curves are estimated on data from rock-fall events. The development of the specific survival curves implements the following working steps:

7.2.2.1 Compiling data on rock-fall events in forested areas.

The concept is based on the detailed guideline for field documentation, given in the RTA contribution: Perzl et al. (2018) – Documentation of forest and other woody land along trajectories of non-destructive rockfall. (2018).

Woody land cover units, like forest stands with relative uniformity, and the internal structure of woody vegetation of these units of homogeneity have to be compiled and documented along rockfall trajectories (real rockfall paths) from the farthest block deposit to the starting point of the rockfall hazard (the center of the scar). Depending on the classification of land cover unit the amount of collected data varies. Clearing areas and non-forested areas are registered by their length and position. For the forested sections, the required parameters for TORRID are determined.

The key parameters of TORRID are:

General parameters:

- **EventID** [enumeration]: The EventID is the connection to the 3W+ Standard of the individual documented rockfall event: What happened? When did it happen? Where did it happen? The + stands for all additional documented information – which is part of the national (individual) database and not needed to develop TORRID. For the development of TORRID only the EventID as integer number is important.
- **RockID** [enumeration] The RockID counts the individual rocks within a documented event (EventID). That means one to many RockIDs can be related to one EventID. (One to many rocks from the same release area for the same event date...).
- **UnitID** [enumeration] This is the consecutive number of the unit of homogeneity. Similar to the RockID it means that one to many UnitIDs can be related to one EventID. The UnitID correspond to the pre-investigation to gather information about vegetation and other surface cover. (no forest, forest 1, forest 2, ...). For more than one unit please start to count the UnitID with 1 from the documented rock deposition upward. This means the highest UnitID number of a certain RockID equals to the release area, and the lowest UnitID number equals to the deposition.

For each unit the following rock-fall related parameters need to be compiled:

- *Length* of unit [m]: This refers to the horizontal length of the related unit (UnitID) passed by the related rock (RockID) for a documented event (EventID). So for each RockID at minimum one UnitID exists and therefore one horizontal length can be stated.



- *Height of unit [m]*: Vertical (drop) height of the related unit (UnitID).
- *Description*: Provides information about the unit. For example: rock cliff, grassland, dense forest, maquis shrubland, ...

Forest related parameters for each forested unit are:

- *Basal area [m²/ha]*: The angle count sampling method (ACS) (Bitterlich, 1984) and, in case of young wood and shrubs below callipering limit of ACS, tree diameters at breast height (DBH) from stem surveys on fixed area plots are used to calculate the basal area.
- *Stand density [N/ha]*: The method is set up for determination of the number of wood plants per ha regardless of plant size.
- *Species composition*: Stand composition can be specified as proportions of basal area or canopy cover on base of the proposed survey.
- *Ratio high forest/shrub forest*: The method enables the calculation of the percentage of different types of land cover of the total length of the rockfall path.
- *Top height [m]*: Different indications of the height of the woody vegetation like the top height may be calculated on base of the surveys.

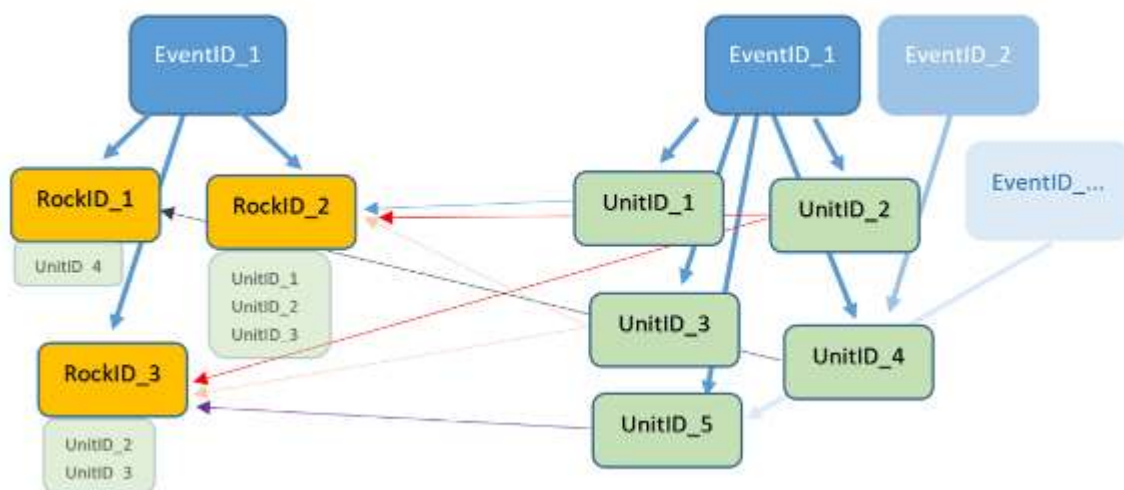


Figure 25: Graphical concept of how EventID, RockID and UnitID are related.

Figure 25 shows the general concept on compiling data for the development of specific survival curves in the framework of TORRID – RocktheAlps. For each rock-fall event one to many rocks might exist and each rockfall event might have passed one to many units. However, other events might have also passed the same units as documented for prior events. So to say: “Which units passed the considered rock(s) of one single event?”

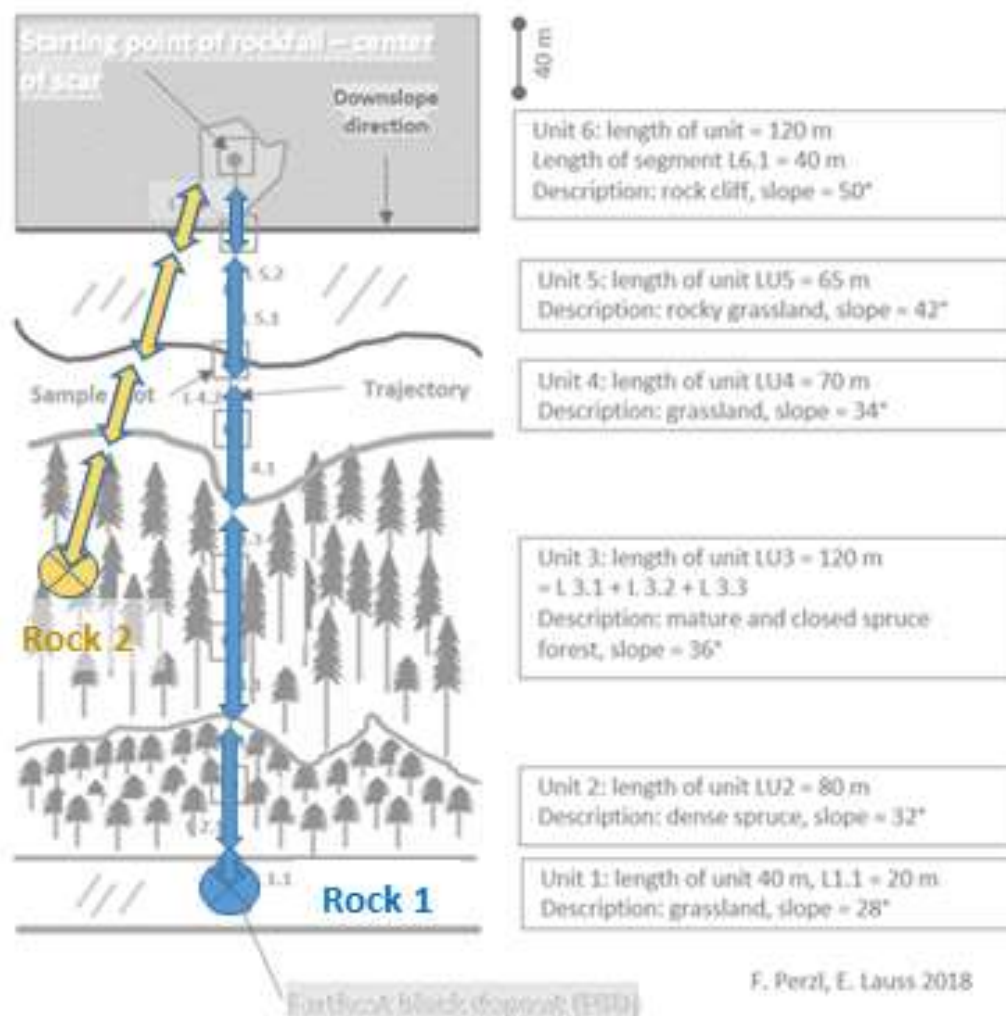


Figure 26: Example and sketch of event situation providing path and unit information for two rocks based on the same rockfall event.

7.2.3 Defining forest stands by grouping their most significant forest parameters according to rock fall

In a next step, forested units are analysed in order to find homogenous groups of forest parameters respectively forest stands. We herewith assume that forest stands grouped by similar forest key parameters provide similar protection effects against rock fall.

7.2.4 Specify survival curves for the grouped forest stands

The clustered forest stands form the basis for creating specific survival curves (Figure 27).

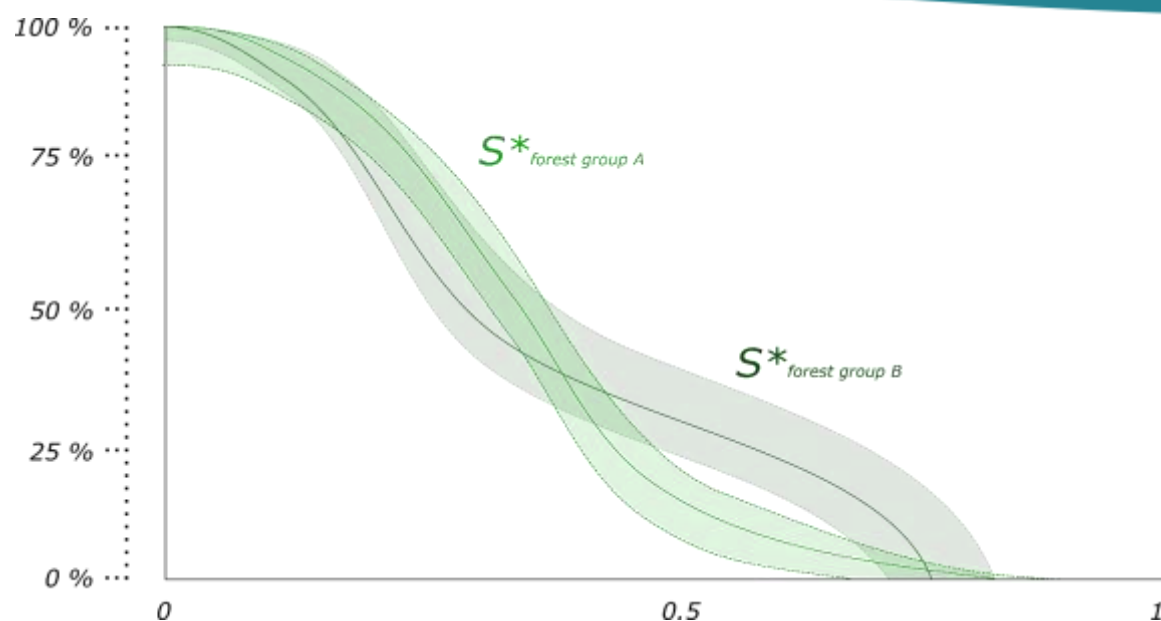


Figure 27: Concept of normalized specific survival curves for two different forest stands which have been grouped by their most significant forest parameters according to rock fall.

7.3 The forest roads information database system

Jurij Beguš - Slovenia Forest Service

Forest management is largely based on the accessibility of the territories where the resource is located, usually provided by different types of forest roads. Proper knowledge of their main characteristics and maintenance status can help not only the correct management of remote sites, but also to rapidly intervene in case of emergency. This is the case of most of protection forests.

In Slovenia a forest road is, by definition, an infrastructure intended basically for forest management, enabling rational transport of wood assortments, non-categorized according to the regulation of public roads and it is recorded in the Register of Forest Roads (RFR).



Figure 28: Forest road in Slovenia.

According to the Forest report 2018, Slovenia has 12.625 km of forest roads, which are not only important in a forest-management sense but represent a national wealth, which needs to be properly planned, constructed and maintained. Slovenia Forest Service collects information about all existing forest roads within the Country regardless of forest property.

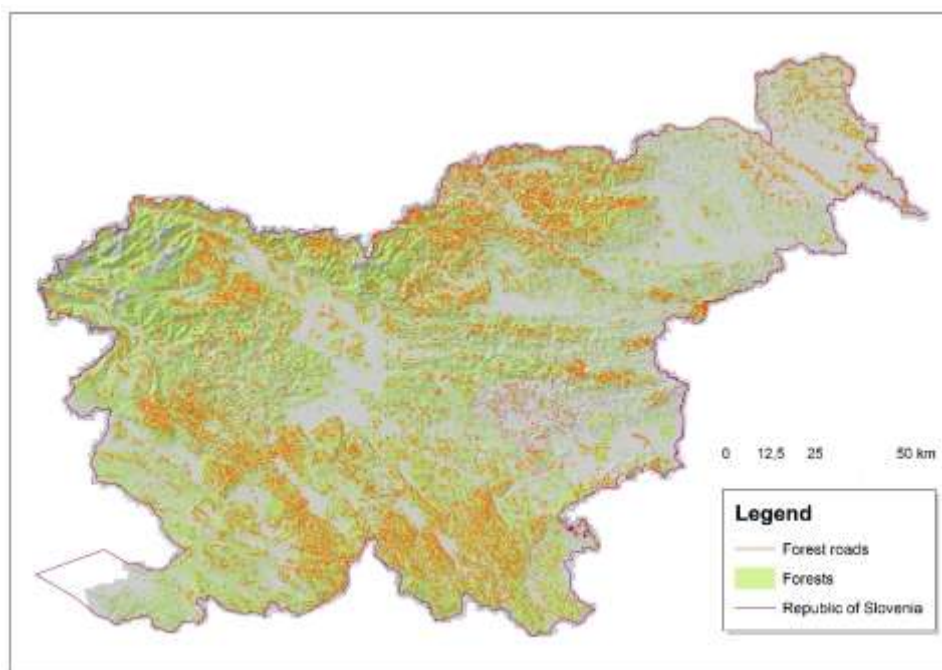


Figure 29: Map of Slovenia's forest road network.

Aspiring towards optimal forest management, good information is needed. An overview of the entire data can only be achieved with an adequately designed information system and for this purpose, Slovenia Forest Service (SFS) has designed a forest roads information database system.

7.3.1 The scheme of the forest roads information system

Forest roads information database system is designed in a way that suits three basic principles: it is open, dynamic and modular. Concerning forest roads, it contains four modules:

- Forest roads
- Forest roads maintenance
- Skid trails
- Fire protection roads

The information system is structured as a relational database and it is composed of spatial objects and their attributes. Elements of the system are linked by an identification field, which is the road code. The basic unit of the system is forest road in its entire length.

7.3.2 Data model of Forest roads module (RFR)

Information about forest roads are managed for Slovenia in whole and are not divided accordingly to smaller organizational or administrative units.

General data:

- Road (ID, name, length, category, min. width, max. inclination, public character, year of construction)
- Ownership

Administrative and forest management division:

- Forest management unit
- Local unit
- District
- Local community

Data about objects on the road and its constructing elements:

- Drainage systems
- Bridges and other objects
- Crossovers
- Road traffic signs

7.3.3 Graphic part of the RFR

Spatial or graphic part is based on digital recording of the forest roads network, through which attributive data are transferred into the spatial part by a linking field and are compared with other data. Graphic recording of the forest roads network is the basis called “information layer of the forest roads network”, or shorter, a digital forest roads network. It can be introduced into different spatial data of raster or vector contents. The importance of the graphic part of the information system is in its ability of data visualization, drawing of maps of different contents and scales, analysing, modelling and collecting data.

7.3.4 Digitalization of the road graph

Graphical lines of forest roads have been digitalized mainly from DTM or as GPS tracks. In the last few years the process of correcting the graphic lines of forest roads according to LiDAR-derived DTMs is under way. Slovenia, indeed, can take advantage of the LiDAR products derived from a nation-wide flight, recorded in 2015, with a resolution of 2-3 points per square meter within forested areas. This is enough to recognize the road paths under canopies and improve graphic layer of forest roads.





Figure 30: Difference between digitalization from DTM and LiDAR track.

7.3.5 Web application for RFR

A web application for RFR was designed according to the data model from 2012. The application allows three main “windows”: graphical part, explorer and detailed display for attributive data. The main objectives for the creation of a web application are: to have a comprehensive basis for planning (openness, new lines of forest roads, etc), to allow direct collection of data (e.g.: damages on forest roads, etc), to enable usage for different users (forest owners, forestry operators, local communities, firefighters, etc). In brief, having a comprehensive and user-friendly system, that could offer an overview of the situation across the whole country and in real time, allowing an easy combination of different information and full transparency to the user.



Figure 31: Web application for RFR.

Web application allows editing, printing and filtering the data (according to defined permissions). Besides general data of forest roads, the system includes information about:

- Administrative boundaries, entities
- Forestry borders (compartments, forest management units...)
- Cadastre
- Traffic regime, regime of use
- Public roads, suitable for forestry operations
- Other forestry information
- Nature protection areas, Natura 2000
- Forest stands
- Objects on the road
- Traffic signs
- Other information

7.3.6 Conclusions

When designing the forest roads information system, we have tried to capture all necessary data that enable a complex overview of the forest roads network. The system is open and dynamic, therefore is not difficult to include supplements which later could be important and useful. At the moment, it is of utmost importance that the system contains

basic data about forest roads and their division into different spatial entities, because they are the basis of the entire information system. Big steps ahead have been made with the introduction of web application of Register of Forest Roads, which is constantly updated with new data obtained from new technologies (e.g. LiDAR).

8.1 Map of protection forests of the Trento province from snow avalanches.

Ruggero Alberti, Paola Comin, Andrea Leoni, Alessandro Wolynski – PAT-SFF; Fabiano Monti, ALPsolut.

Forests can play an essential protective function against the impacts of natural hazards. Identifying the protective forests has a crucial importance in order to define proper technical and silvicultural measures able to maintain or improve their function. The active mitigation function of the forests could completely prevent the triggering of an avalanche; otherwise, the passive function (i.e. increasing the friction of the snow mass while moving) is quite limited or null in case of large sized events. In the province of Trento (Italy), an automated approach for avalanche hazard mapping has been developed for identifying the forests playing a role in avalanche risk mitigation.

A digital elevation model with a spatial resolution of 5 m was used for the terrain classification; a layer identifying the forested areas was derived through a GIS approach making use of the forest map and CHM (Canopy Height Model).

The climatic snow cover characteristic, necessary to define the fracture heights, were derived by analysing the data of 30 manual weather stations, which have a recorded dataset longer than 20 years. Five micro areas were individuated, reflecting the differences between micro-climatic characteristics.

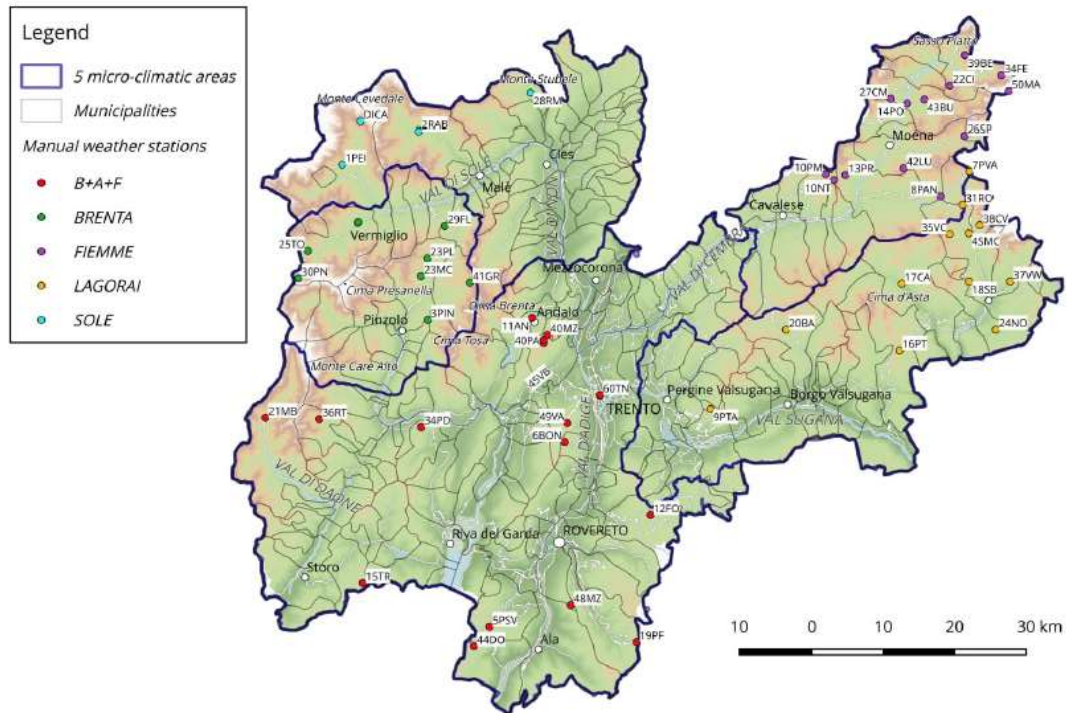


Figure 32: Subdivision into micro climatic areas of the Trentino Province.

Two scenarios were individuated for snow avalanches: a frequent scenario (return period of 10 to 30 years) and an extreme scenario (return period of 300 years).

For each scenario, the probable releasing areas were automatically defined using a GIS algorithm considering both the forest effects and not (few assumed that forest canopy cover >50% can prevent avalanches release).

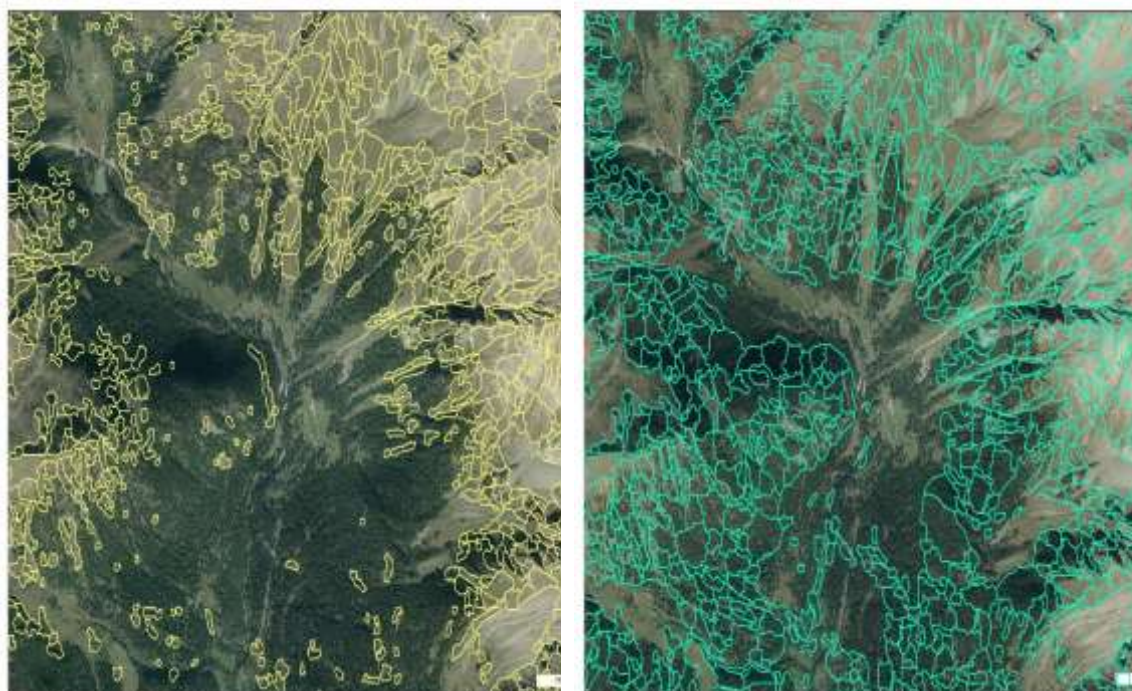


Figure 33: Potential Avalanches Release Areas without (left) and with forest effect (right) for the frequent scenario (30 years, Cogolo)

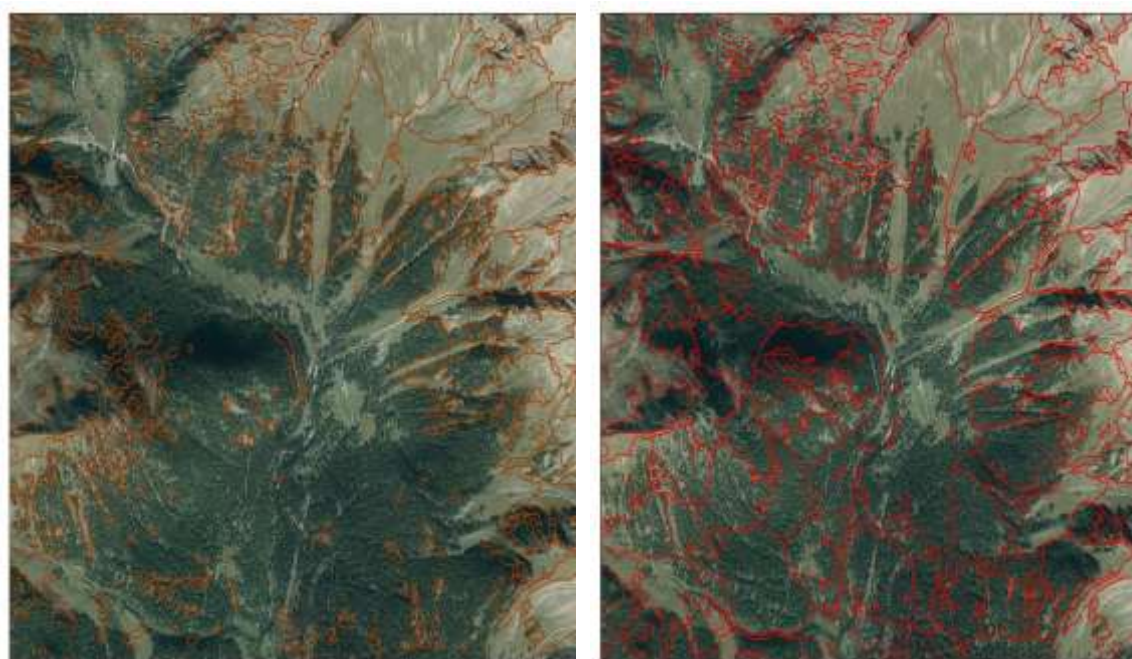


Figure 34 Potential Release Areas without (left) and with forest effect (right) for the extreme scenario (300 years, Cogolo)



By comparing the results obtained considering both the forest effects and not, the forests playing an active function for avalanche risk mitigation were identified.

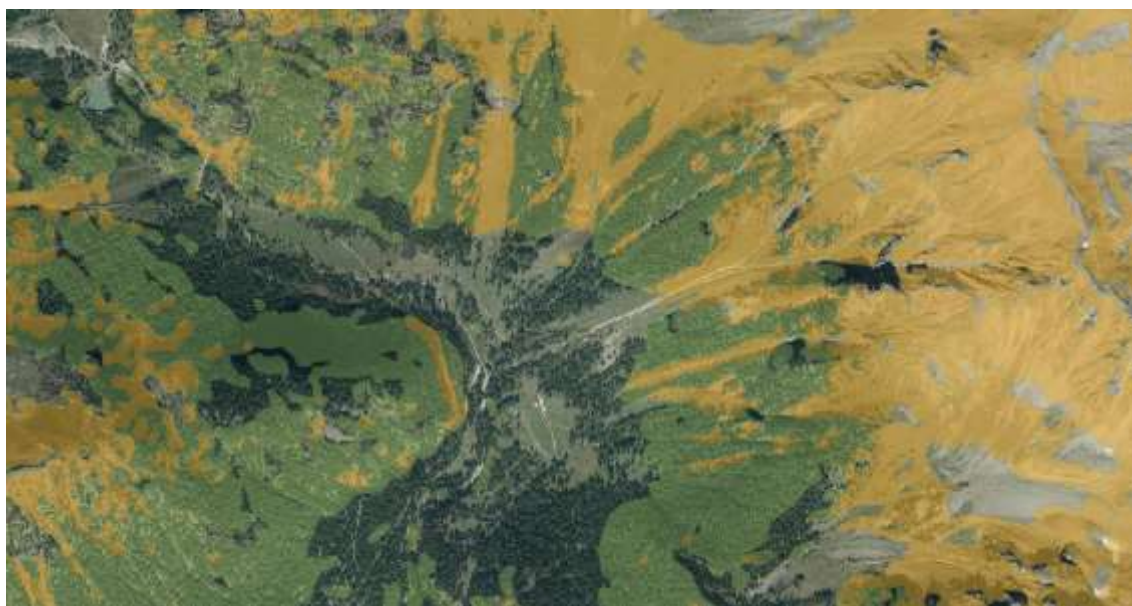


Figure 35: Potential release areas (orange) and protection forests (forest preventing avalanches release; green) - frequent scenario (30 years, Cogolo).

Then, the avalanche dynamics model RAMMS was used to simulate the avalanche tracks and deposition areas for both returning periods of 30 and 300 years. The fracture heights were defined depending on the micro-climatic area and the elevation of each avalanche releasing area.

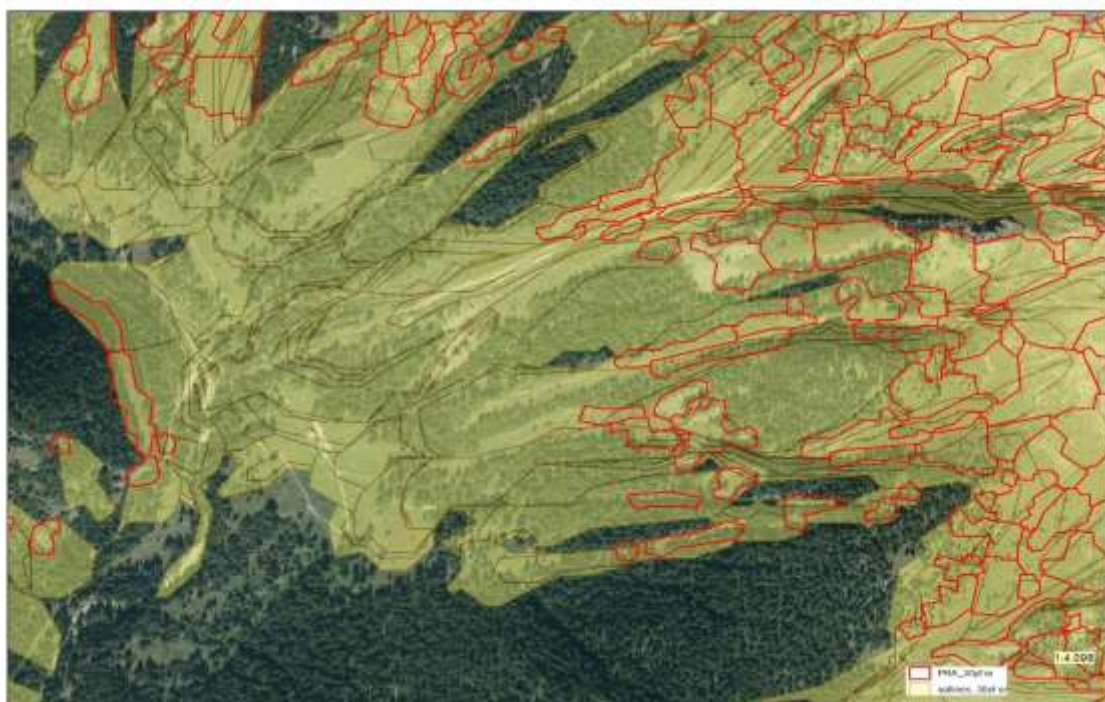
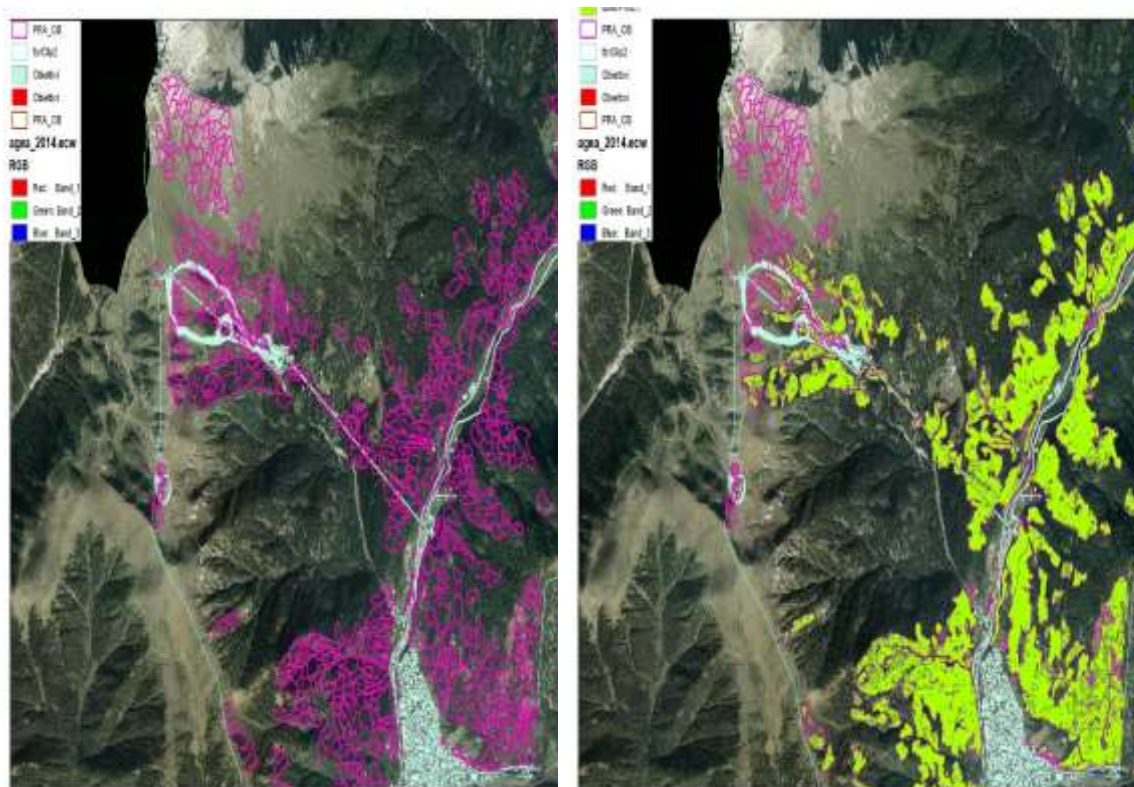


Figure 36: Potential release areas (red) and potential avalanches outlines (yellow) - frequent scenario considering actual forest effect (30 years, Cogolo).

These results were tested with existing historical avalanches database, showing that the model matches the reality at a very good level.

To define forests who directly protect objects like buildings and infrastructures, for each scenario we first selected the objects inside avalanches outlines (simulated without considering the effect of the forest), each one linked to the related potential release area; then we overlapped the selected release areas with forest cover $>50\%$, which are supposed to prevent avalanches release.

Overlapping with forest cover $<50\%$, it is possible to find the potential protection forests, which could protect the object in the future when minimum canopy density will be reached.



Valley).

become very useful also for Civil protection and snow avalanches management.

are less precise than expert analysis.

9 APPENDIX 2: CASE STUDIES

Appendix 2 contains the technical sheets of the main case studies, completed with a brief description of the site and the specific applications carried out by the local partners.

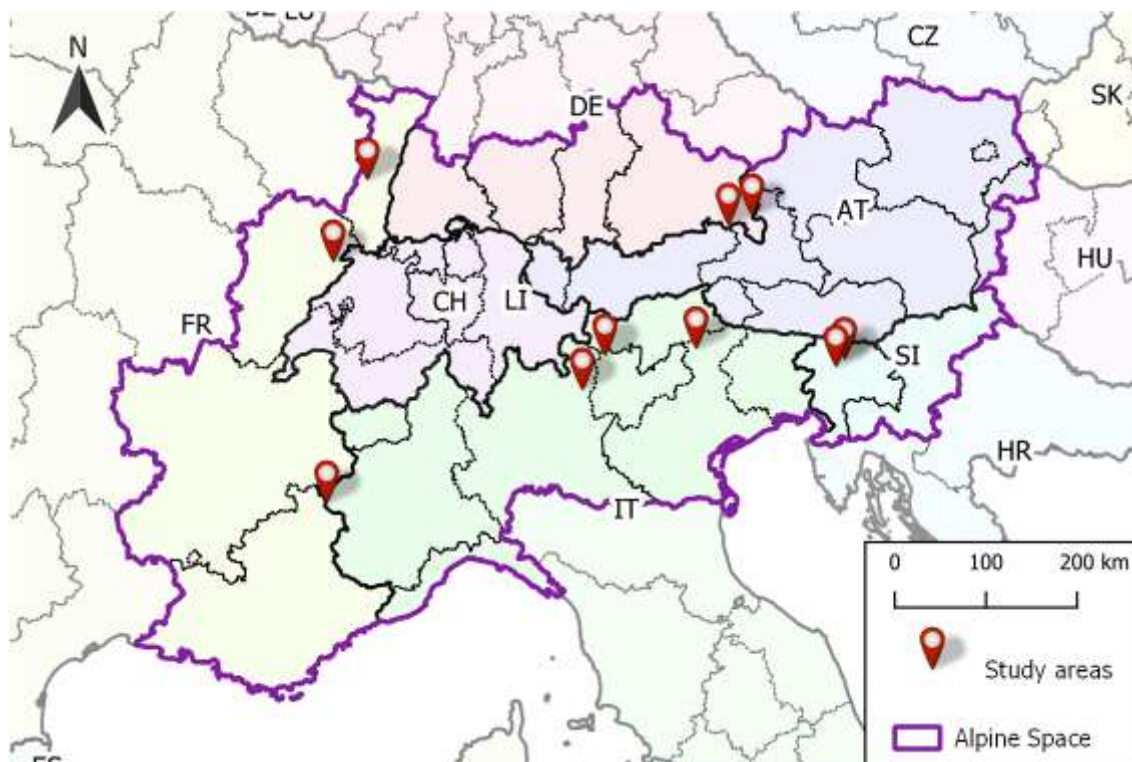


Figure 38: Overview of the main study sites taken in consideration during the project.

Table 5: Summary data related to the main case studies.

Country	Site/Province	Size (ha)	Height range (m.a.s.l.)	Forest type	Reference partner
DE	Seewände (Seegatterl)	1.7	780 – 880	Mixed high stand	LWF
DE	Strailach (Berchtesgadener Land)	2.0	460 – 540	Mixed high stand with shrubs	LWF
F	Kaysersberg Vignoble	16.45	Na	Na	BRGM / IRSTEA
F	Noirefontaine	Na	Na	Mixed broadleaves coppice	BRGM / IRSTEA
IT	Cogolo (Trento)	5.2	1730 – 2320	Montane mixed conifer high stand	PAT-SFF
IT	Colcuc (Belluno)	27.6	1360 – 1710	Montane mixed conifer high stand	TESAF
IT	Cevo (Brescia)	8	Na	Mixed coppice	ERSAF
IT	Cesana torinese (Torino)	8	1480-1640	Montane mixed conifer high stand	DISAFA
SLO	Baška grapa	160.8	Na	Montane mixed beech high stand	UNILJ
SLO	Jelovica	0.44	1010 – 1170	Montane mixed conifer high stand	ZGS

9.1 Seewände (DE)

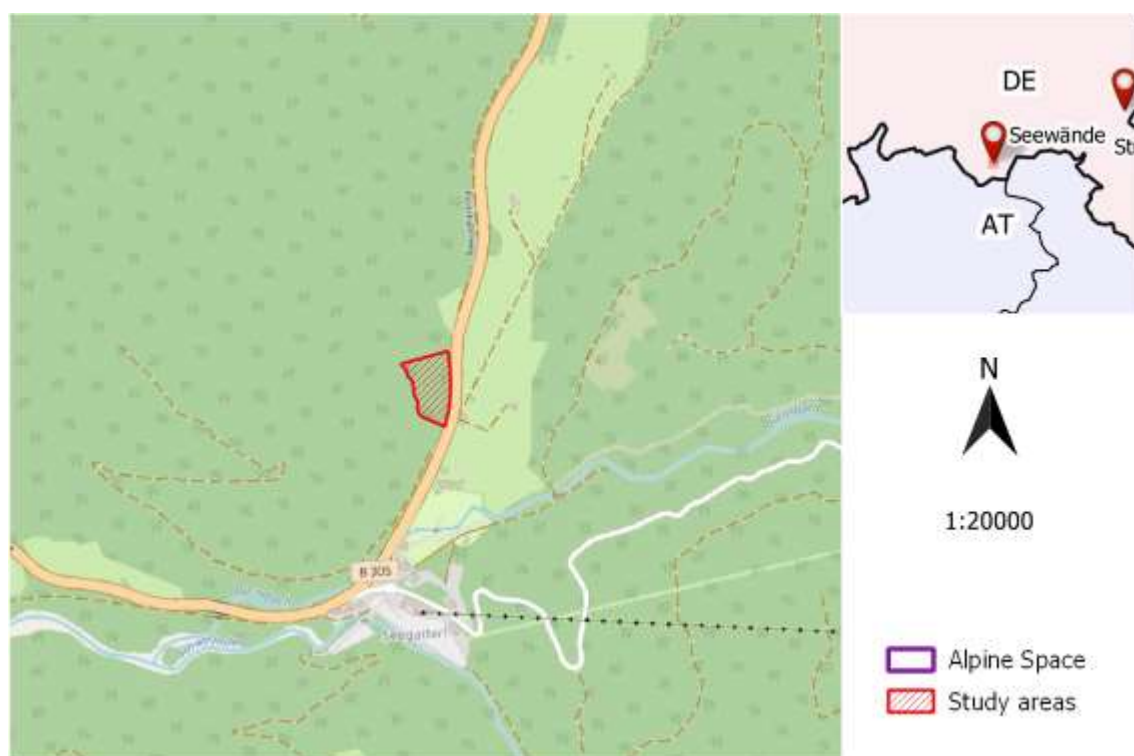


Figure 39: Overview of the Seewände site (northern Alps, DE).

Site description

The pilot area is located in the municipality Reit im Winkel (Seegatterl district), on an east-oriented slope situated in the Bavarian part of the Northern Limestone Alps. The forest is classified as potential protection forest and is composed mainly of common beech (*Fagus sylvatica* L.) and Norway spruce (*Picea abies* (L.) Karst.). A federal road passes at the bottom of the slope. The pilot area was selected, among other things, to test terrestrial laser scanning (TLS) in a steep mountain forest environment. A large subplot (0.4 ha) was scanned with a Leica MS50 MultiStation. The resulting pointcloud was analyzed with the open-source software 3D Forest¹. The main analysis steps were: automatic segmentation of the whole point cloud into point clouds representing individual trees, visual check of plausibility, manual cleansing and automatic extraction of dendrometric parameters. The resulting stem positions and tree diameters were compared to the reference dataset obtained from traditional field measurements. Results from this pilot area show that almost all trees

¹ Trochta, J.; Krůček, M.; Vrska, T.; Kral, K. (2017): 3D Forest: An application for descriptions of three-dimensional forest structures using terrestrial LiDAR. PLoS ONE 12(5): e0176871

could be detected through TLS. With only a few exceptions, diameters are in very good agreement between TLS data and field measurements.



Figure 40: Leica MS50 MultiStation scanning the forest.



Figure 41: Vertical section through the forest surveyed by terrestrial laser scanning.





Figure 42: Visualization of a scanned forest in the software 3D Forest.

Economic evaluation

- Selected economic approach:

The **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the asset at risk, that is a road, is considered as the relevant damage potential.

- Selected time period for the evaluation:

25 years. This value is the result of several discussions with the partners of the project.

- Exposed assets:

The only asset is a 202 m stretch of **road**, which is frequented all year round.

- Protection forests:

N/A



- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Road	59	87	0.90

- Value of the exposed assets:

The road value data is missing. Of the movable property and the value of human life defined according to the ERSAF/ETIFOR project partners, presence of average annual daily traffic card machine (Bau und Verkehr, 2019).

Asset	Unitary value immovable [€/m]	Exposed area Immovable [m]	Unitary value movable [€]	Presence probability movable [h]	Presence probability people [h]
Road	-	-	20,039	84	168

FOREST MANAGEMENT

Total forest management costs are € 30,659, as detailed in Figure 43.

Estimated costs for protection forest management at site Seegatterl Seewände		
area [ha]	1,7	
A) initial investment to enhance protection function	calculation	total costs [€]
cutting and debarking trees, storing them, perpendicular to the slope	20 stems each 1,5 m ³ = 30 m ³ ; labour costs 50 €/m ³	1500
planting trees	1000 plants, each 3,50 €	3500
costs because cut down trees cannot be sold, german: "Nutzungsverzicht"	30 m ³ at 75 €/m ³	2250
road closure during forest management activities	1 day additional cost due to extra way for every participant of average daily traffic: 16,3 km longer way * 0,30 €/km travelcosts * 2023 vehicles per day = 9892 €/day	9892
	Sum	17142
costs per hectar [€/ha]	10084	
B) following investments to maintain good level of protection	calculation	Kosten gesamt [€]
total costs every 10 years [€/ha]	half of costs for forest management + 1 day road closure	13517
costs per hectar [€/ha]	7951	

Figure 43: Detail of the forest management expenses.



RESULTS

Overall avoided damage [€]	69,833
Overall discounted stumpage value [€]	30,659

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **100,492 €**
- *Unitary Protection Value* **60,211 €/ha**
- *Yearly Protection Value* **1,880 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The results obtained are in line with those in the literature



9.2 Strailach (DE)

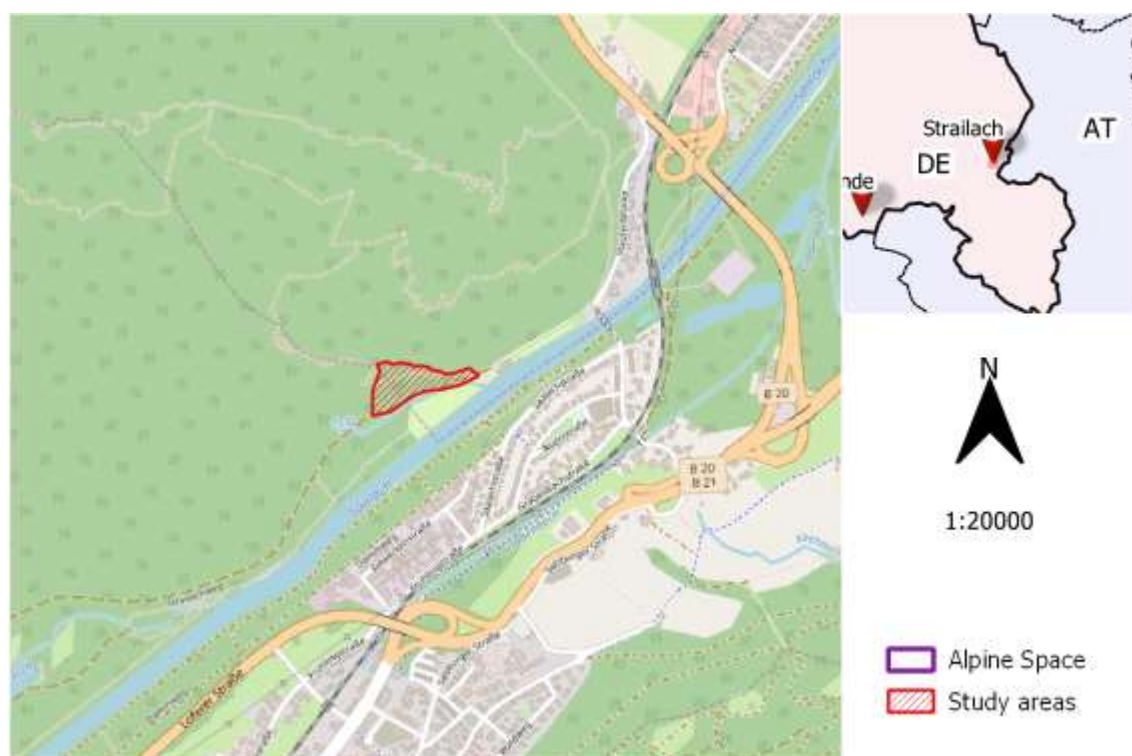


Figure 44: Overview of the Strailach site (northern Alps, DE).

Site description

The pilot area is nearby the municipalities of Piding and Bad Reichenhall (district of Berchtesgadener Land) located in the Bavarian part of the Northern Limestone Alps. The southeast oriented site has an extent of 2.0 ha and covers altitudes between 460 m.a.s.l. and 540 m.a.s.l. The forest is classified as potential protection forest. The forest can be characterized as an unevenaged, mixed forest stand with high structural variability and a high proportion of shrubs. It is primarily composed of common hazelnut shrubs (*Corylus avellana* L.), European ash (*Fraxinus excelsior* L.), common beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.) Karst.), and European larch (*Larix decidua* Mill.). Besides the forest, additional rockfall nets protect the forest road, which is frequently used for recreational purposes, and the campground at the valley bottom from rockfall events.

The site was selected amongst others to test the extraction of dendrometric parameters through TLS in very dense stands with understory. Compared to other forests that have been scanned, working with TLS in this site was more difficult than usual: the high abundance of hazel shrubs forms a dense stand, leading to a relevant shading effect and therefore limiting the possibilities to extract accurate forest parameters. For this reason, it has been opted to rely on a tachymetric survey and manual field measurements.



Figure 45: Common hazelnut shrubs make an important contribution to the protection effect at the study site.

Economic evaluation

- Selected economic approach:

The **RCM** is adopted because the rockfall nets were installed to protect a forest road, frequently used for recreational activities and a campground.

- Selected time period for the evaluation:

25 years. This value is the result of several discussions with the partners of the project.

- Exposed assets:

The only exposed element is a 307 m stretch of **forest road**, frequently used for camping and recreational activities.

- Protection forests:

The forest structure is comparably complex with partly dense shrub vegetation composed of *Corylus avellana* L..



- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Forest road	527.1	529.1	0.273

- Desired protection level from stakeholders:

stakeholders desire a medium because the event threatens a road of secondary importance, moreover the kinetic energy released by the boulder is not high, therefore there is not even damage to the roadbed, also due to the small size of the falling boulders (95° percentile). The level of protection desired by stakeholders is **50 %**.

- Score of the protection demand survey:

The score is **21 points**. From a qualitative point of view, the stakeholder directly involved, a federal administrator, was particularly sensitive to the protection of the area, so the score obtained made it possible to increase the desired level of protection to a higher class, **from medium (50 %) to high (75 %)**.

FOREST MANAGEMENT

There are **no forest plans** available and the absence of data did not allow ASFORESEE to calculate this item, so the value within it is 0 €.

RESULTS

Overall discounted building cost without forest [€]	2,079,421
Overall discounted building cost with forest [€]	1,244,801.25
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:



- *Monetary Protection Value* **0 €**
- *Unitary Protection Value* **0 €/ha**
- *Yearly Protection Value* **0 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The result obtained is 0 € because the forest does not play an effective role against rockfall. Therefore, its value is equal only to the expenses of forest management, which, not being present in this case, attribute a zero value to the protective service.

9.3 Kayserberg (F)

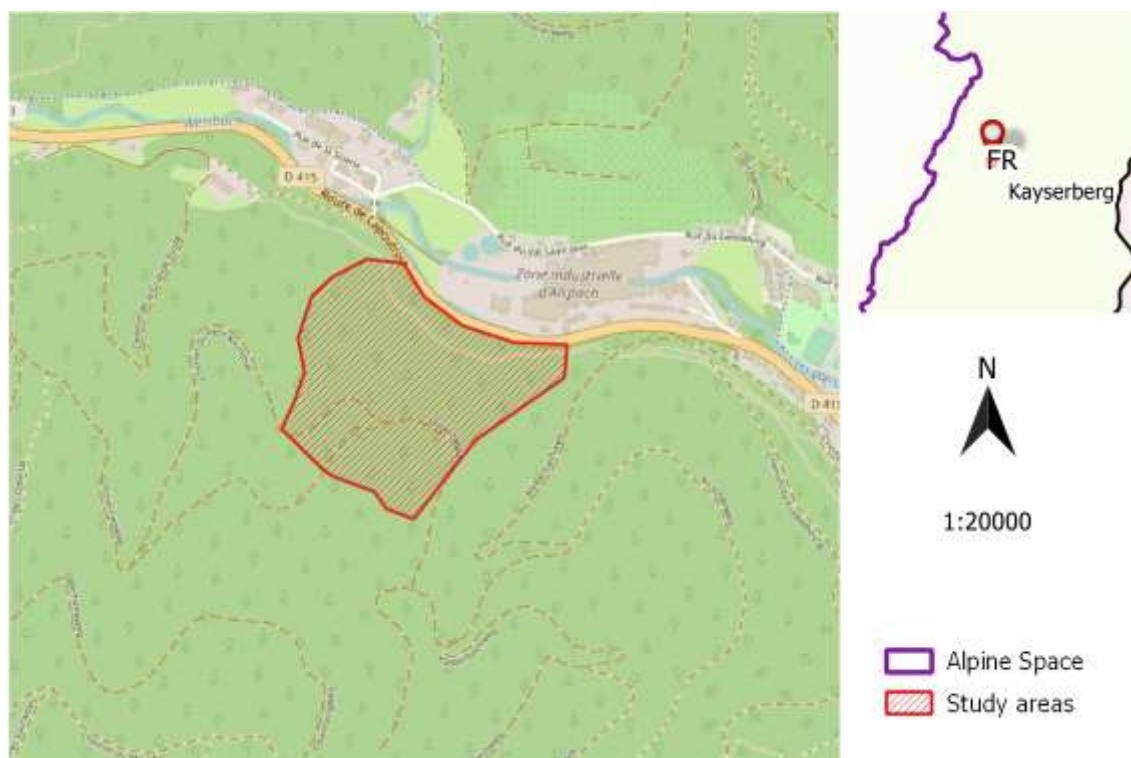


Figure 46: Overview of the Kayserberg site (eastern Alps, F).

Site description

The case study is located near the road RD 415, on a portion located in the south of the municipal territory of Kaysersberg Vignoble. This site was chosen because of the occurrence of one event having reached the road (year 2017), this road is one of the three ones allowing to cross the Vosges Massif, and the continuous presence of forest upslope of the road. Above this road, an old mature mixed forest (basal area varying from 25 to 41 mq/ha) is established on a regular slope varying between 29° and 32°. The forest zone is dominated by a scree and four rocky outcrops are locally presents in the forest, each with a height of about 3 m to 10 m.

During the event of 2017, the maximal volume of the blocks that reached the road was of about 0.33 mc.



Figure 47: Forest boundaries and asset at stake.

The forest boundaries as shown in



Figure 47 cover **16.45 ha**. The exposed asset is the road RD 415, 450 m of which are exposed to rockfall risk.



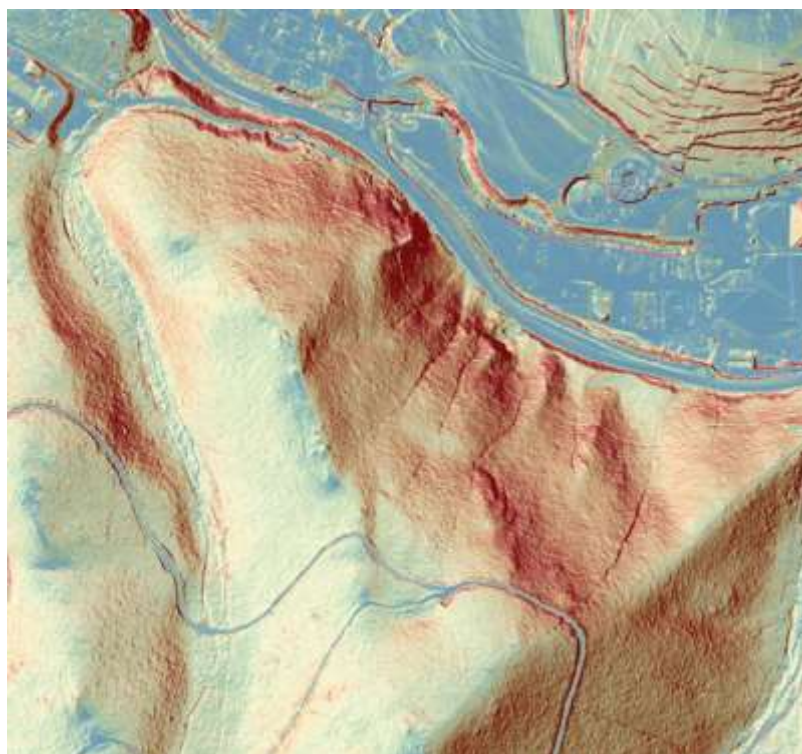


Figure 48: Topography obtained from the LIDAR survey.

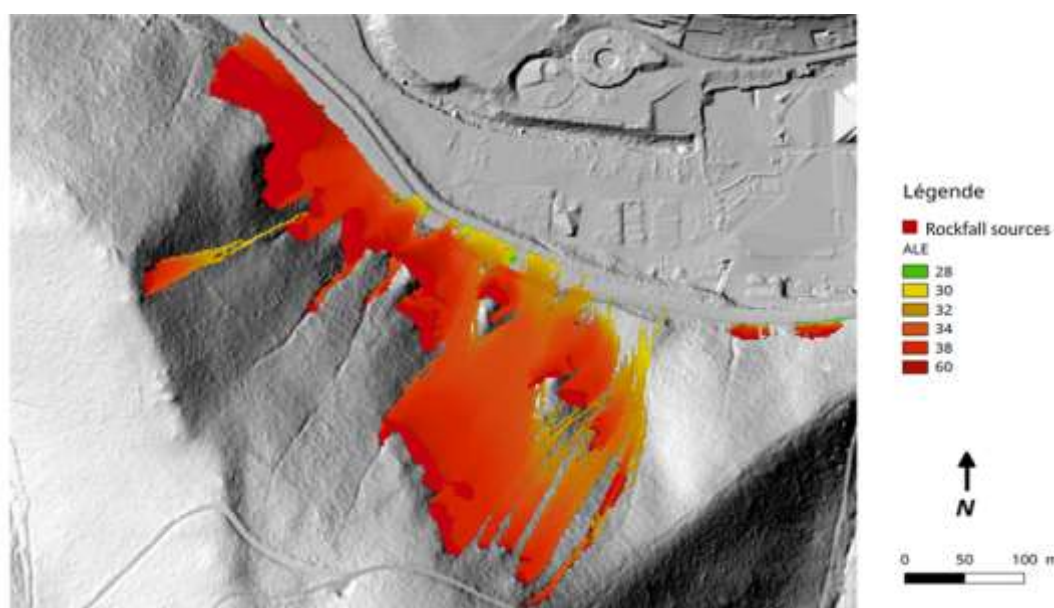


Figure 49: Rockfall sources. This side of the hill produces mainly block of a size inferior or equal to 0.5 mc.

Economic evaluation

- Selected economic approach:



in this case study, an artificial protection is easily implementable and the road to be protected, even if it is quite important for the connection of local territories, is not highly sensitive to the rock fall events. Thus, the **RCM** is the selected approach.

- Selected time period for the evaluation:

the timespan selected for the evaluation is of **25 years**. Considering that it is the service life of a traditional protection structure (rockfall net).

- Exposed assets:

The asset exposed to the rockfall is a portion of the **Road RD415**. It is a two lanes road with a width of about 8 m. The average annual daily traffic (AADT) is of about 10,000 vehicles.

- Protection forests:

The five profiles represented in the following figure are representative of the problems of falling rocks and of the different propagation zones.

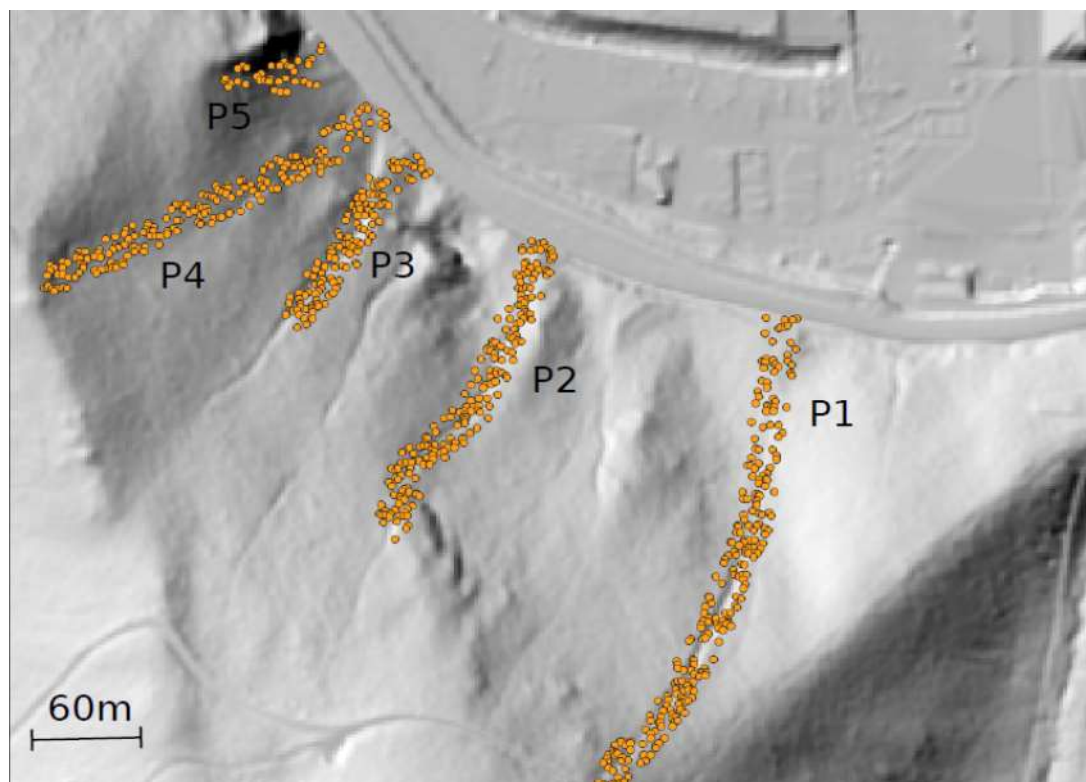


Figure 50: Location map of the five topographic profiles used for the analyses.

A buffer of 10 m on each side of the profiles has been used to extract the identified trees from the analysis of the Lidar data (circles in orange). The methodology used allows to extract the height of the trees identified and to assign them a diameter with an allometric function. The table hereunder provides a description of the current state of the forest in each profile.

Table 6: Stand characteristics in each of the five representative profiles.

Profile	Length [m]	Average diameter at breast height [cm]	Density [trunk/ha]	Basal area [mq/ha]	ORPI
P1	310	28	420	25.88	99
P2	205	25.9	492	25.90	97
P3	130	28	545	33.59	94
P4	224	33.4	464	40.68	98
P5	60	31.9	328	26.26	62

Using the tool ROCKFOR^{net}, in the profiles P1, P2, P3 and P4, the forests stands can provide a protection efficient at 75 % against volumes that are smaller than 0.5 mc. These results are consistent with those obtained by 3D simulation and the distribution of projectiles observed onsite.

- Forest effectiveness against rockfall:

The kinetic energy considered is the one of a falling block having the 95° percentile of the diameter measured in the area. In this site, it corresponds to a block of 0.56 mc. The ORPI index used for calculation is the one corresponding to the worst-case profile.

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Road RD415	198	265	62



- Desired protection level from stakeholders:

stakeholders desire a very high level of protection because the rock falls threaten a primary road for the territory. The minimal level of protection desired by stakeholders is **75 % to 95 %**. The ideal protection level desired by stakeholders is 95 % to 99 %.

In the ASFORSEE model, the input data “Desired Protection Level from Stakeholders” is set at **95 %**.

- Score of the protection demand survey:

The asset owner and manager of the road have carried out the protection demand survey. The score obtained is **19**.

- Discounted cost of the protective structure:

In the scenario without forest, the investment cost of a protective structure providing the expected level of protection would be of € 162,000. This amount corresponds to the implementation of net over a linear of 360 m with an investment cost of € 450 per linear metre. It should be added the cost of felling 350 trees but being in a “without forest scenario” it seems not relevant to include this cost to the investment cost. The maintenance cost corresponds to two inspections per year for an annual cost of € 500. Using these figures over 25 years with a discount rate of 2 %, the discounted cost of the protective structure is of € **171,762**.

FOREST MANAGEMENT

There is **no forest management** in the current situation.

RESULTS

Overall discounted building cost without forest [€]	171,762
Overall discounted building cost with forest [€]	102,821.91
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **68,940 €**
- *Unitary Protection Value* **4,204 €/ha**
- *Yearly Protection Value* **131 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The level of protection offered by the forest in its current state is not enough. The stakeholders and decision makers want to increase the level of protection. They need a decision support to select between two options:

- invest in an engineering solution, which is very efficient but expensive;
- invest in a natural solution, which is less expensive but offers a progressive increase of the protection and a slightly lower level of safety.

The protection value provided by the model correspond to protection service provided by the forest at its current state and does not consider the possible improvement of the protection service that can be reach by implementing a specific forest management. For decision makers it seems that a comparative cost efficiency approach would bring a useful decision support.

9.4 Noirefontaine (F)

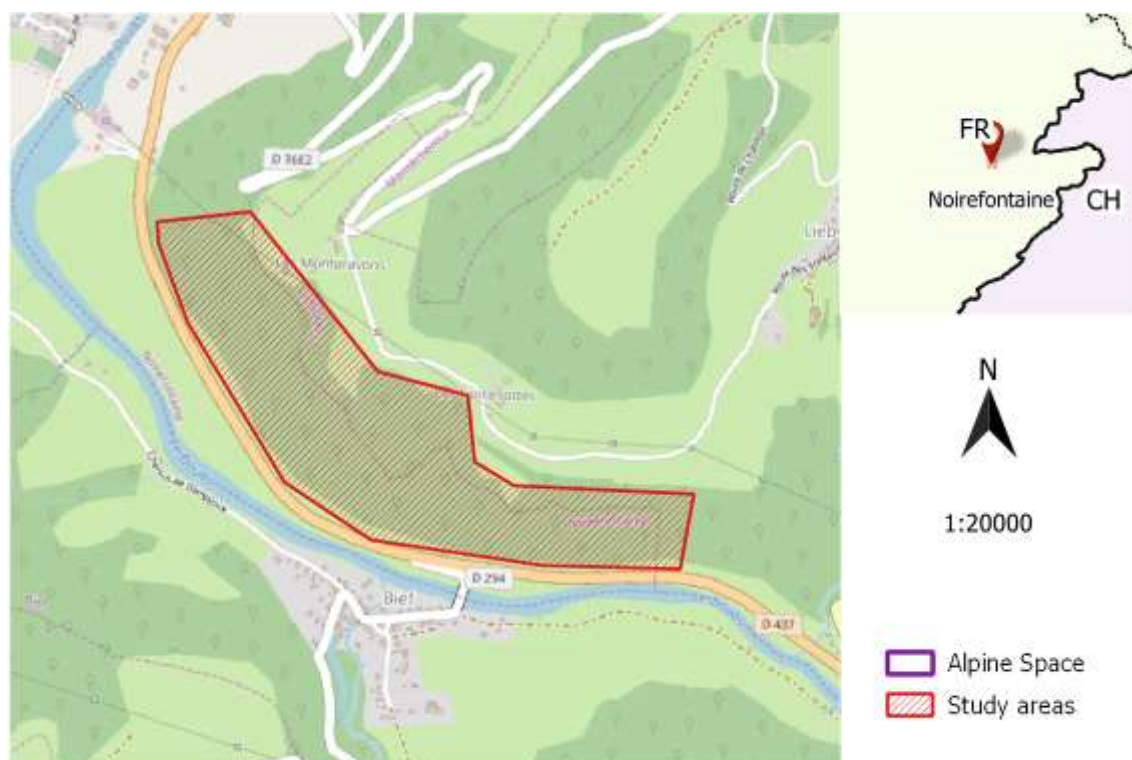


Figure 51: Overview of the Noirefontaine site (eastern Alps, DE).

Site description

The case study is located near the road RD 437, on a portion located in the south of the municipal territory of Noirefontaine. This site was chosen because of the occurrence of two events having reached the road (years 2012 and 2015) and the continuous presence of forest upslope of the road. This road is overlooked by an old railway line forming flat area. Above this railway line, a shallow forest is established on a regular slope varying between 35° and 39°. The forest zone is dominated by three successive rocky outcrops, each with a height of about 10 m to 15 m, separated by low forested areas with a slope like the forest zone.

During the two events of 2012 and 2015, the volumes of the blocks that reached the road were 1.6 m³ and 2.1 m³.

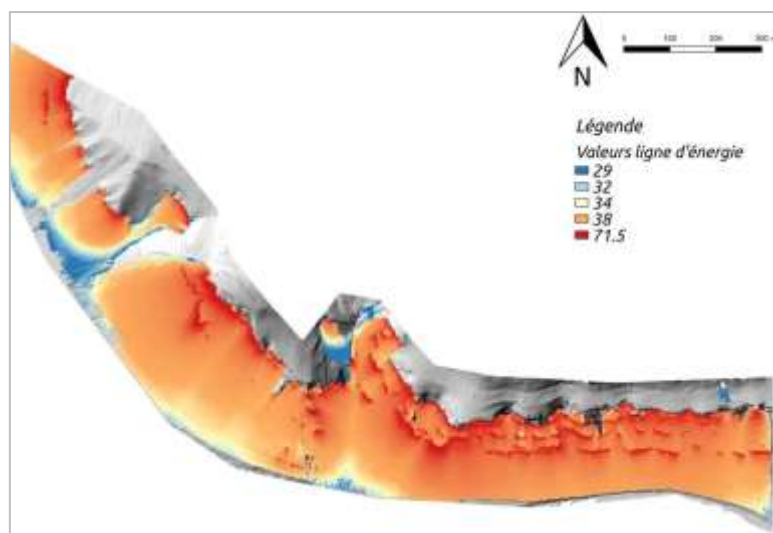


Figure 52: Areas potentially affected by the rockfall hazard of the case study as a function of the energy line value β .

The map of areas potentially affected by the hazard shows that no point on the road can be considered as totally safe. All potential starting points were considered on topographic criteria only. The stability of the rocky compartments is not considered at all in this analysis.

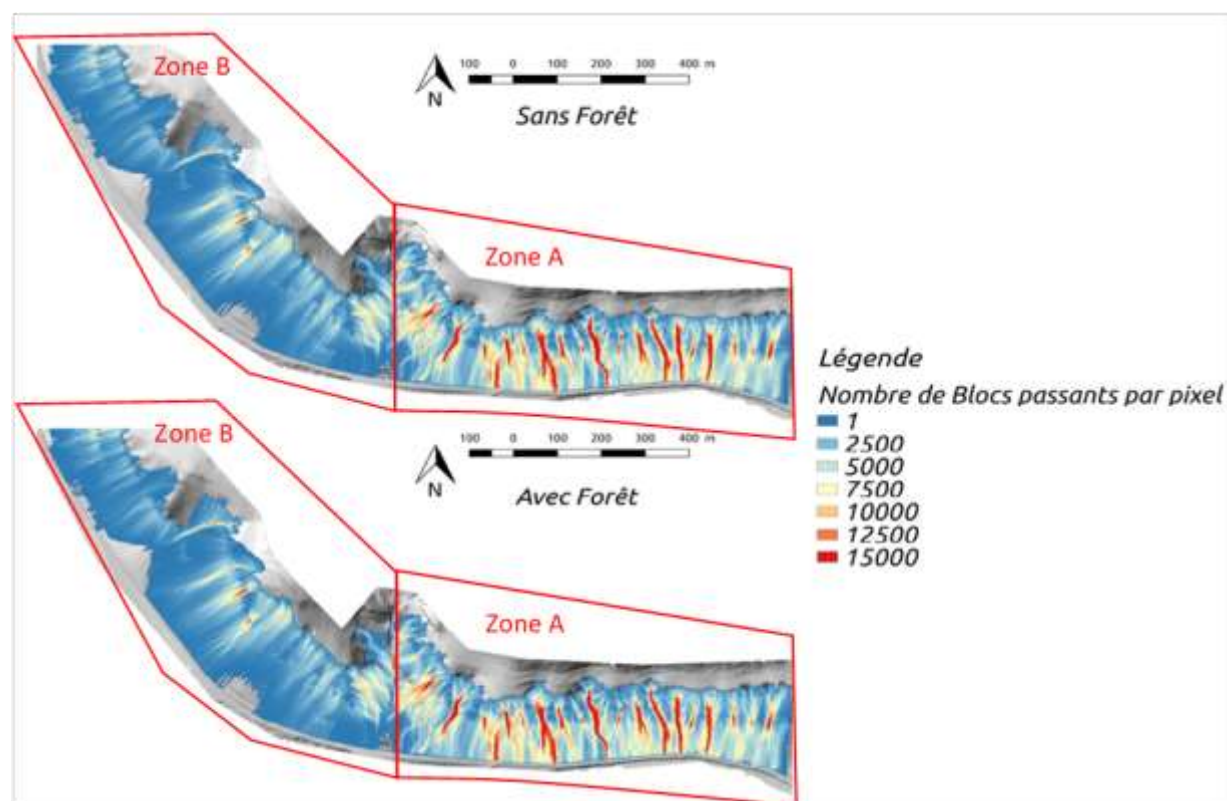


Figure 53: Mapping of block propagation (number of blocks passing) with and without consideration of the forest at the case scale.

Although trajectory simulations quantify only the propagation hazard, the observed difference between zone A and B has an impact on the overall rockfall hazard. Indeed, the global hazard can be considered as the product of the initial hazard by the propagation hazard. In zone A, not only the propagation hazard is higher than in zone B, but the initial hazard is also higher because field surveys have shown a much larger number of blocks at the bottom of zone A than in zone B. These results show that it is not necessary to carry out a more detailed study on zone B because, since this sector is little exposed to the risk of falling blocks, the analysis of the forest protection function is not essential. As a result, the detailed analysis of simulation results was only performed on zone A.

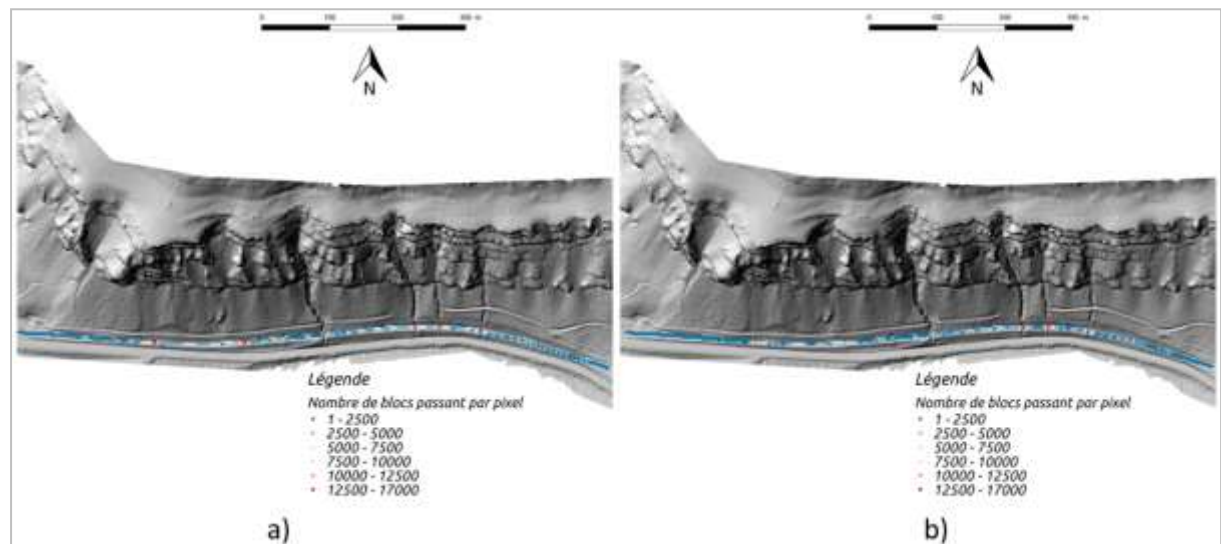


Figure 54: Mapping of the number of blocks passing by cell at the level of the railway on zone A without (a) and with (b) considering the forest.

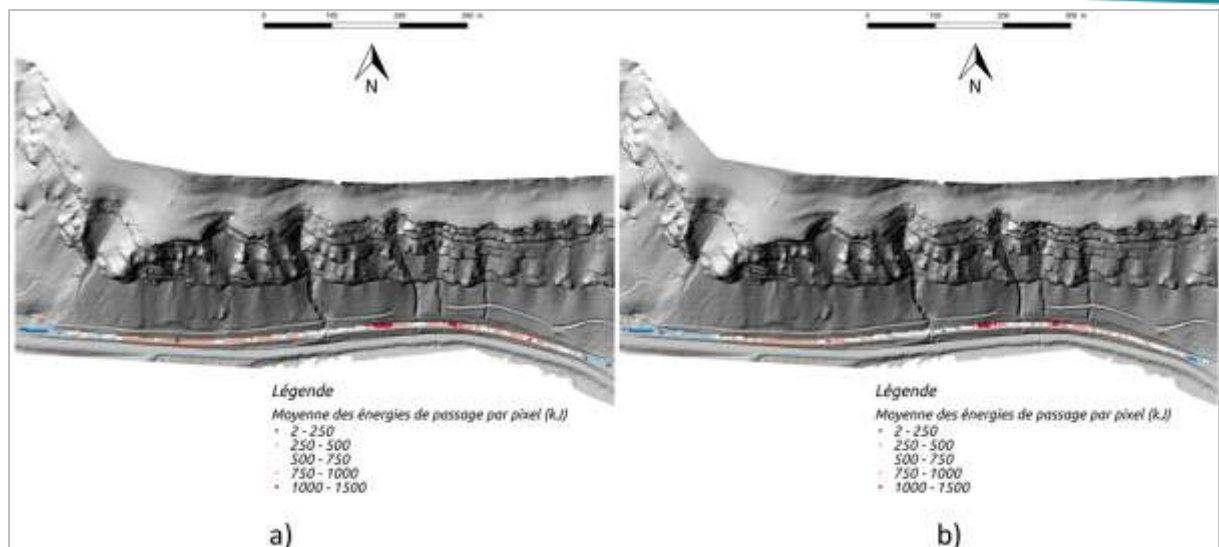


Figure 55: Mapping of the average energies of blocks passing through each cell at the level of the railway on zone A without (a) and with (b) considering the forest.

The comparison of the results obtained, with and without forest, shows the significant contribution of the forest in reducing the number of blocks passing and their energy. This reduction is generally of the order of 1,000 passing blocks. It can reach 5,000 blocks locally. This reduction represents a significant percentage of reduction in the frequency of the propagation hazard.

However, the reduction of the average energy of the passing blocks is small compared with the maximal energies of the blocks (about 4,000 kJ). This average reduction is generally of about 100 kJ to 300 kJ.

Following these events, preconisation for works has been recommended ignoring the protection service provided by the forest:

- implementation of a deformable screen of category 8 (norm NFP 95-308) on a length of 250 m in zone A: € 200,000;
- implementation of a deformable screen of category 7 (norm NFP 95-308) on a length of 1,850 m for the rest of the area (zone A and B): € 1,110,000.

The length of road at stake in zone A (the case study) is of 880 m. Thus, the total investment cost of the proposed protective structure is € 578,000.

Economic evaluation

- Selected economic approach:

The selected approach is the **RCM**.

- Selected time period for the evaluation:

The timespan of the assessment is **25 years**.

- Exposed assets:

The only asset exposed to the rockfall is a portion of the road **RD 457** (880 m). The average annual daily traffic is of about 14,570 vehicles. At the level of the study area, if the road is closed because of a massive rockfall, reasonable alternative routes are possible, with an additional circulation time of about 13 minutes by the south and 15 minutes by the north. An additional time due to congestion must be expected.



Figure 56: View of the asset at stake – Road RD437 at the bottom of zone A.

- Protection forests:

The forest stand is an **old mixed broadleaves coppice**. The basal area varies from 18 m²/ha (average tree diameter of 15 cm and a stem density of 1,019 stem/ha) up to 30 m²/ha (average tree diameter of 18 cm and a stem density of 1,179 stem/ha). The main tree species are *Quercus pubescens* Willd., *Fagus sylvatica* L., *Carpinus betulus* L., *Fraxinus excelsior* L., *Acer pseudoplatanus* L. .

The forest offering a protection service reduces significantly the number of blocks passing (reduction of 40 % of the frequency) but it is less efficient in reducing the energy of blocks passing through. The kinetic energy developed by the falling block having the 95° percentile of the diameter measured in the area (about 1.5 mc) is reduced of only 20 % as shown in the following table.

- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Road RD437	800	1,000	0.90

- Desired protection level from stakeholders:

stakeholders desire a high level of protection because the rock falls threaten one of the primary roads for the territory, but alternative itineraries can be easily used in case of closure of the road. The minimal level of protection desired by stakeholders is **75 % to 95 %**. The ideal protection level desired by stakeholders is 95 % to 99 %.

In the ASFORSEE model, the input data “Desired Protection Level from Stakeholders” is set at **95 %**.

- Score of the protection demand survey:

the survey has been filled by a manager of the road department within the general council of the Doubs sub-region. The score obtained is **20**.

FOREST MANAGEMENT

There is **no forest management** in the current situation.

RESULTS

Overall discounted building cost without forest [€]	4,404,502
Overall discounted building cost with forest [€]	2,404,856
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **520,200 €**
- *Unitary Protection Value* **28,900 €/ha**
- *Yearly Protection Value* **902 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The level of protection offered by the forest in its current state is far from enough and can't be used for building up an effective safety strategy based on the forest management. As the stakeholders and decision makers want to increase the level of protection, then the only adapted option for this site is to Invest in a 100 % engineering solution, which is very efficient but expensive. This conclusion is coming from the fact that if the current forest can significantly reduce the number of passing projectiles, it's not the case about the energy reduction of the projectiles able to reach the road. With a potential reaching kinetic energy value of 800 kJ considering the current forest, a mixed engineering-natural solution using rockfall nets fixed on trees is not possible.

The protection value provided by the model correspond to the forest at its current state and does not consider the possible improvement of the protection service that can be reach by implementing a specific forest management. Aspects to analyze and consider for the future development of the model are:

- how to integrate the potential evolution and consequences of adapted forest management into the reduction of maintenance costs of the engineering solution;

how adapted forest management can allow for the future replacement of rockfall nets to be installed on site.

9.5 Cogolo (IT)

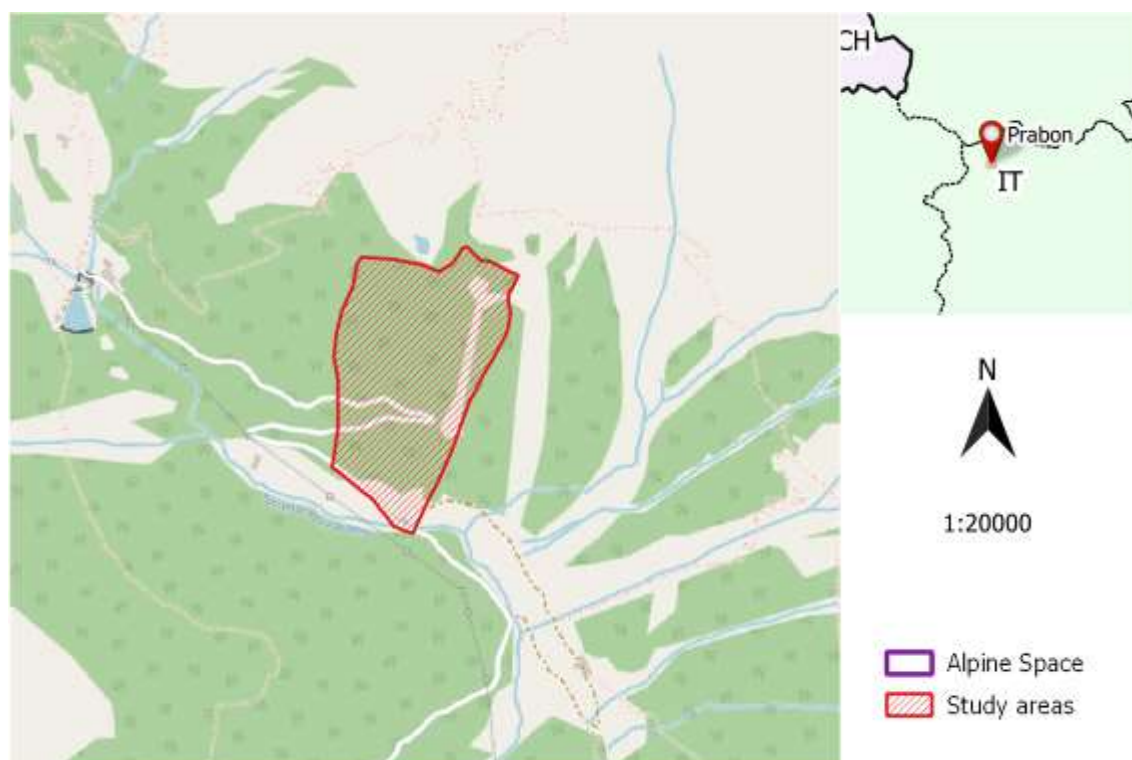


Figure 57: Overview of the Cogolo site (central Alps, IT).

Site description

The case study is a forest on a steep hill slope, in a small valley called “Val dela Mare”, inside Stelvio National Park in the province of Trento.

The valley is important for tourism and becomes very popular during summertime. At the top of the valley, above the study area, many trekking paths and the “Malga Mare” restaurant attract tourists, and a hydroelectric power station exploiting the water of Careser lake is continuously maintained and guarded by workers and staff, so it has to be reachable all year long by the asphalt mountain road which connects the valley to the nearest village, Cogolo.

The study case focuses on a forest stand protecting a road sector not provided with defence structures such as, for example, nets.

In the upper part of the area above the road, several cliffs generate rockfall events. Due to the morphology of the slope and the heterogeneous distribution of rock stack zones, forest stands with different density and opened grasslands, the behaviour of the rockfall phenomena is diversified within the area.

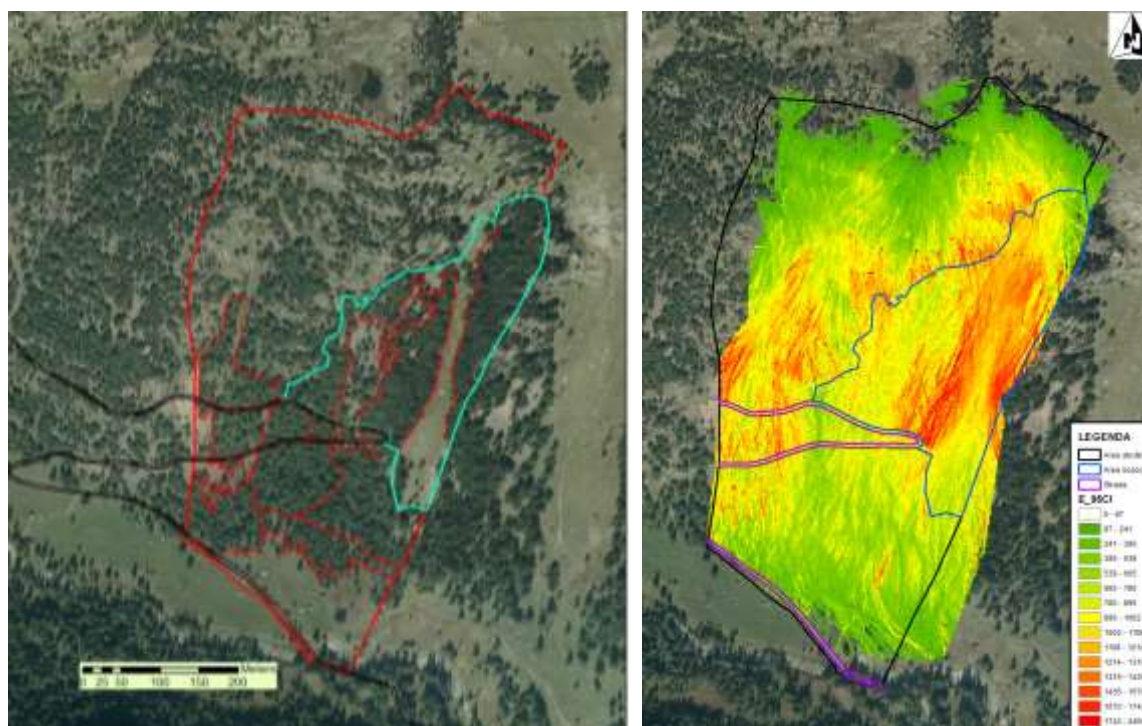


Figure 58: On the left, the study area “Prabon” with its different homogeneous units (red polygons) and the sub-area analysed (blue polygon). The sub-area was defined by quick simulation in Rockyfor 3D (right).

The whole study area is 23,67 ha, of which 5.2 hectares represent the sub-area of release and runout of rocks from the source to the selected road sector. The sub-area was defined by a quick simulation in Rockyfor 3D, which shows the trajectories of single rocks potentially reaching the road sector.

The altitude is quite high (1730-2320 m.a.s.l), representing a typical high mountain environment of coniferous forest under the treeline, and, shrubs, grasslands and rock crests above it.

Forest stands in the sub-area are uneven-aged, composed by Swiss pine (*Pinus cembra* L.) and European larch (*Larix decidua* Miller), with an average DBH of 33 cm and an average tree height of 16 meters. The average density is around 500 trees/ha and the composition is about 70% Swiss pine and 30% larch.

Rockfall simulations with and without forest were conducted using Rockyfor 3D, in order to compare number of block passages stopped and the kinetic energy dissipated by the actual forest cover.

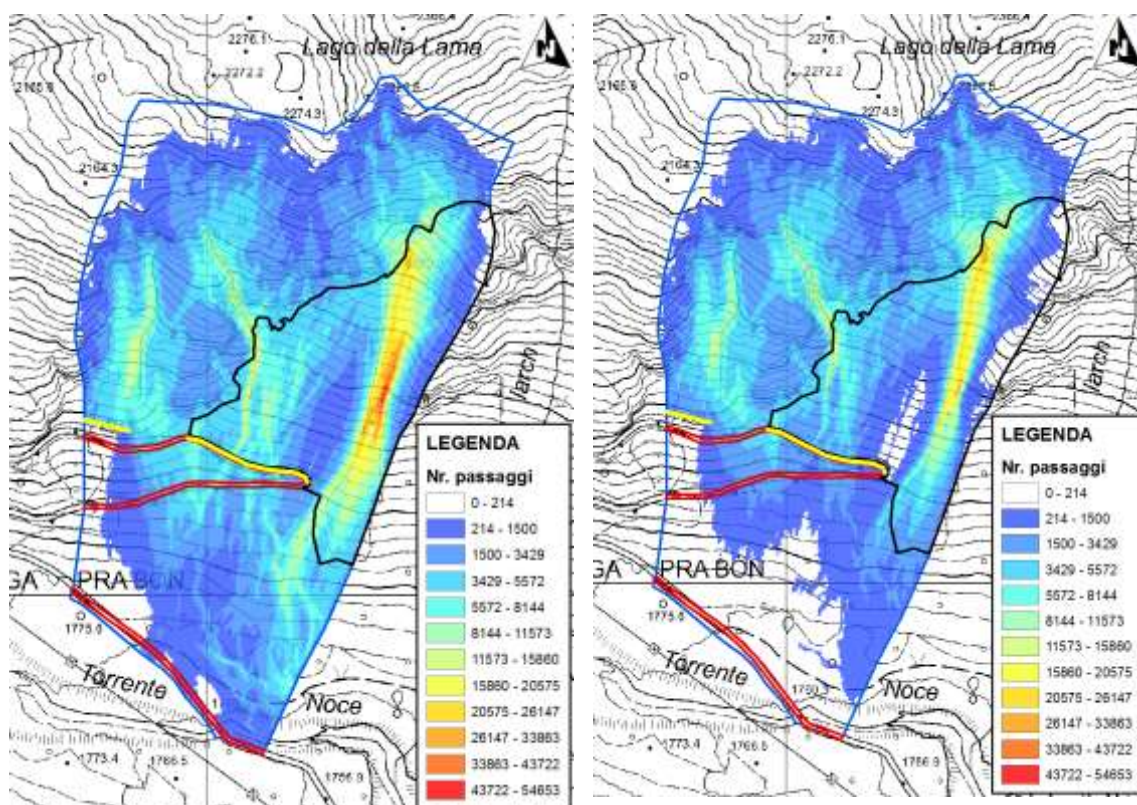


Figure 59: Number of rock passages in a no-forest scenario (left) and in a scenario with the actual forest cover (right) in Prabon area.

The specific efficiency of the forest stand above the selected road sector was defined by setting on the sector 3 virtual nets (nr. 2, 3 and 4 in Figure 60), and calculating the ORPI index (which expresses the total cumulative kinetic energy developed) with and without forest.

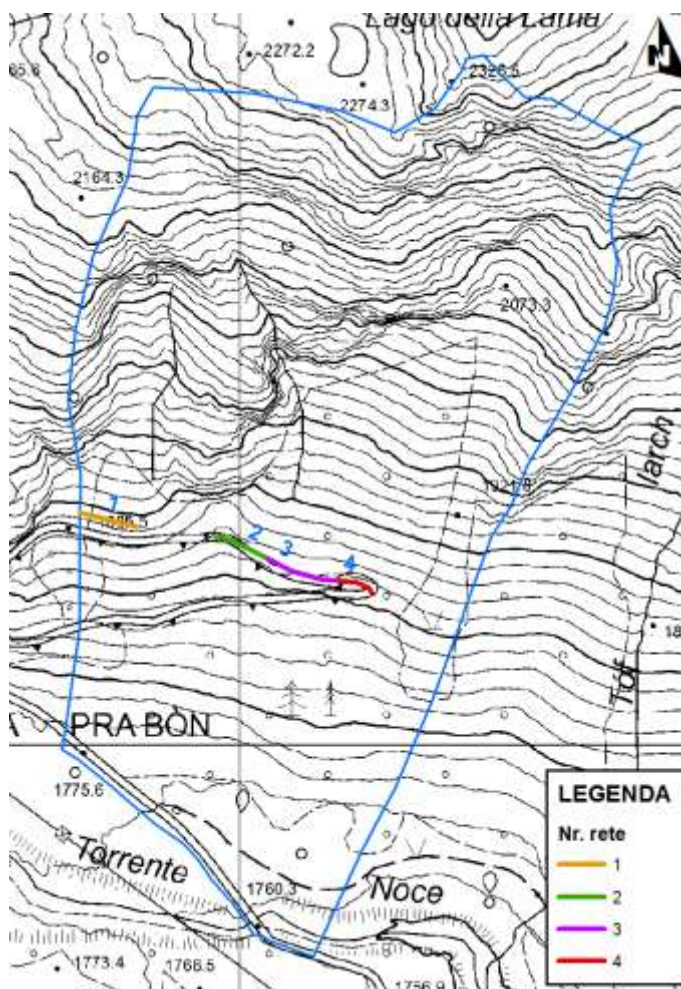


Figure 60: Position of the virtual nets 2-3-4 in correspondence to the selected road sector; net number 1 is a real existing net in another road sector.

The simulation showed 1,149.000 kJ rockfall from the upper zone of the area to the road sector (net). 243.841 kJ rocks reach the road sector in the scenario without forest, and 127.746 kJ with forest: the forest thus stops 116.095 rocks above the road sector.

These rocks generated a cumulative kinetic energy (ORPI index) of 48,136.146 kJ in the scenario without forest, and 28,876.819 kJ in the scenario with forest: the actual forest is therefore able to reduce 40% of the cumulated kinetic energy developed by rockfalls.

Economic evaluation

- Selected economic approach:

The **ADM** has been chosen this approach because it is possible consider indirect perspectives linked with forest functions, for example tourist and leisure functions of the

forest (connected with human passages on the road). Addition to the forest functions, the approach considers also the lack of economic income for the restaurant and the increase of costs for the hydroelectric power plant from a blocked road by a rockfall event.

- Selected time period for the evaluation:

25 years, according to the life expectancy of the protective structure.

- Exposed assets:

It's a part of the **road** that passes through the protected forest. The asset is large about 3 m for a length of 140 m of asphalt road. No guardrail is present in the part of the asset.

- Protection forests:

Total area is **5.20 ha** and the forest is an **uneven-aged stand**, with an average DBH of 33 cm. The average density is around 500 trees/ha and the composition is 70 % *Pinus cembra* L. and 30 % *Larix decidua* Miller;

- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Road	1,986	2,048	0.40

- Value of the exposed assets:

The data was taken from interview with local forest station and from technical office of the municipality of the area.

Asset	Unitary value immovable [€/]	Exposed area immovable [m]	Unitary value movable [€]	Presence probability movable [h]	Presence probability people [h]
Road	750	140	20,039	1.4	4.8



FOREST MANAGEMENT

All forests of Cogolo municipality are management by a **Forest Management Plant**; in the forest of the case study it is not planned any kind of forest management due to steepness of the slope, the distance from the road and the low quality of the trees.

RESULTS

Overall avoided damage [€]	46,787
Overall discounted stumpage value [€]	11

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **46,799 €**
- *Unitary Protection Value* **9,000 €/ha**
- *Yearly Protection Value* **281 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

Meetings with local stakeholders and experts will be held in autumn. At a first stage of testing the tool, we can just put in evidence several aspects of the working mechanism of the tool:

- it would be useful to include also indirect damages (helicopter costs for transporting the workers of the hydroelectric power and lack of income for 2 mountain restaurants on the top), globally at least 30.000 €/month in summer;
- it would be useful a guide with the concepts and formulas used to define the outputs, so that the user can verify if an input figure is accurate enough or not.



9.6 Colcuc (IT)

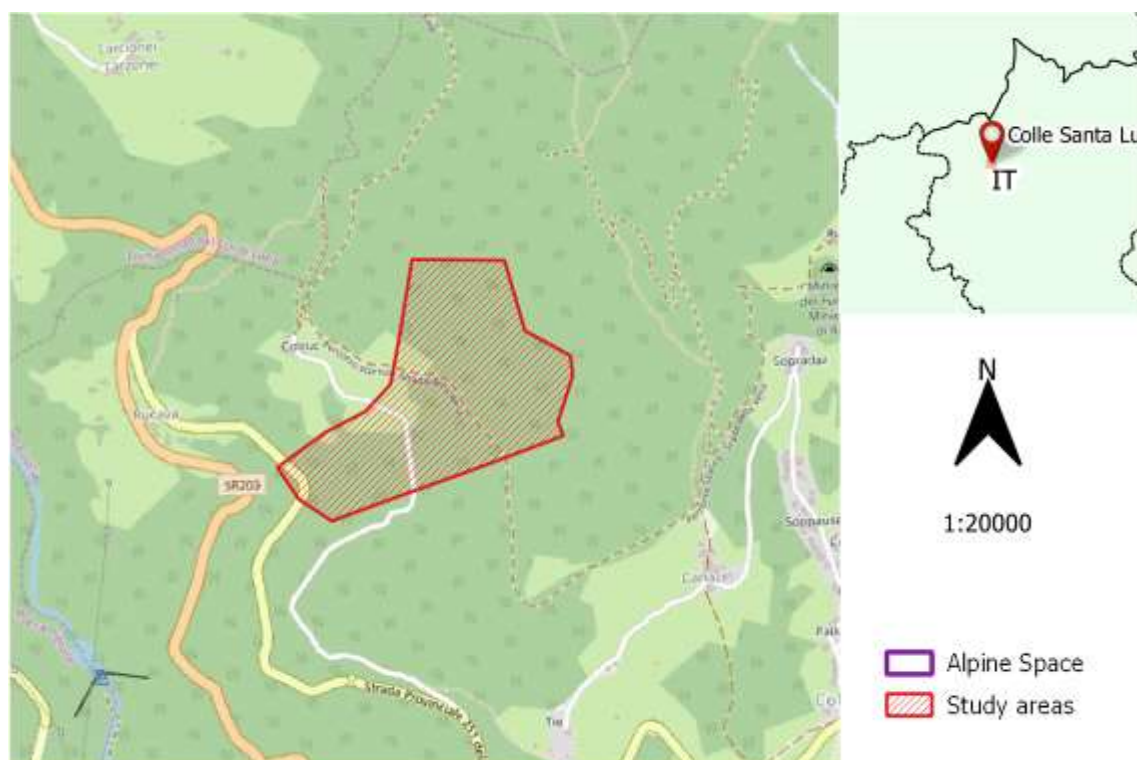


Figure 61: Overview of the Colcuc site (eastern Alps, IT).

Site description

The study site is located on Monte Pore, close to Colcuc, municipality of Colle Santa Lucia, Belluno province (Italy). The site is on the southwestern slope of the mountain and its elevation ranges between 1360 and 1710 m a.s.l. The main forest species is Norway spruce (*Picea abies* Karst.), with sporadic presence of European larch (*Larix decidua* Mill.) at higher elevations. On the 2nd of April 2004 a massive landslide (appr. 4000 m³ of rocky material) affected the site that has been therefore defined as “active” for rockfall concern.

Several infrastructures cross the study site, such as a hiking/biking trail, a local road and a regional road. After the mentioned event, some concrete infrastructures were built in order to minimize the risk to the stakeholders.

The field surveys included two perpendicular transects within which have been collected the position and dimensions of 242 rocks, and position of 288 impacted trees, plus height and dimension of the scars. Furthermore, 15 circular sample areas (12 m radius) were set for the collection of the basic forestry parameters necessary for the creation of the input layers for the Rockyfor3D simulations (e.g. trees density, DBH, species dominance).

Additional information was derived from the available remote sensing sources (i.e. LiDAR, UAV) in order to obtain a high resolution DTM and DSM (up to 1 m), and photo orthomosaic (cell size 0.20 m). Finally, different layers (CHM, tree density, roughness, etc) have been obtained in order to spatialize the data collected in the field and create the input rasters necessary to the 3D rockfall simulations.

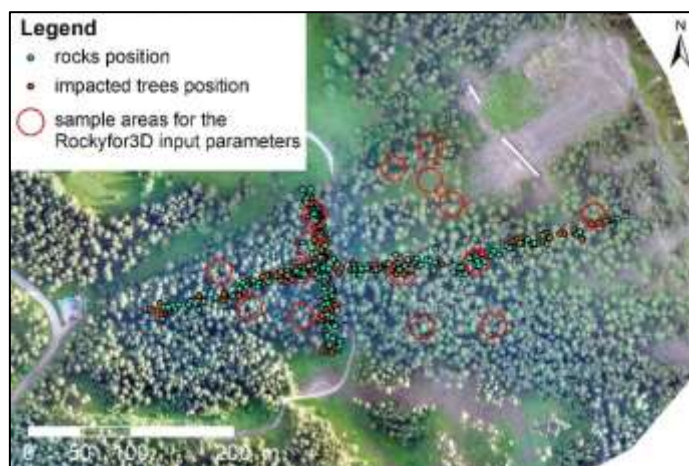


Figure 62: Distribution of the sample areas across the sites and the position of rocks' position (green dots) and impacted trees (red dots).

The preliminary results show that accurate field data collection, and their spatialization based on remote sensing data, have been proven effective in the achievement of realistic rock fall simulations. First simulations, indeed, show a good agreement between observed and predicted rockfall deposits.

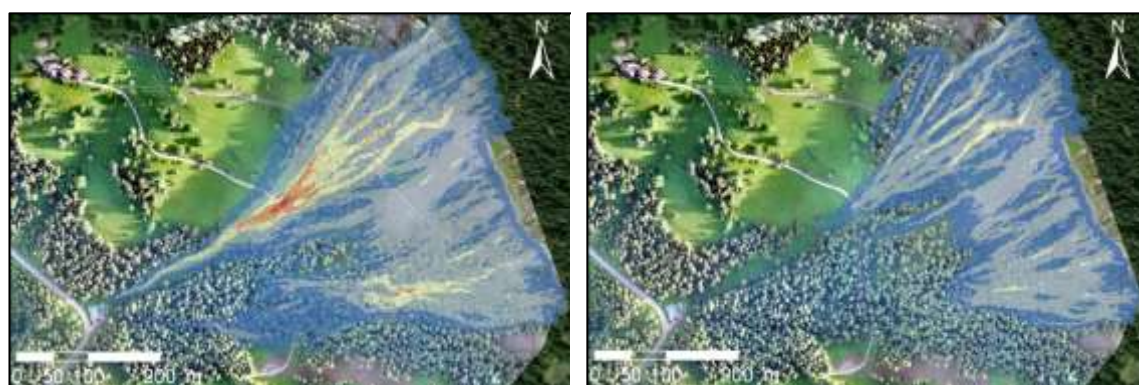


Figure 63: Rockfall simulation without forest (left) and with forest (right). It is visually possible to notice the blocking effect of a forest stand against rockfall.

Post event analysis

The occurrence of the Vaia Storm on the 29th October 2018 led to the destruction of approximately half of the forest cover within the area. A LiDAR flight carried out few months later offered the availability of post-event data, which is progressively being analysed in order to detect the damage on the forest stands and the effects on the protection efficiency of the remaining ones.

Economic evaluation

- Selected economic approach:

The **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the vulnerable element is of some importance.

- Selected time period for the evaluation:

25 years. This value is the result of several discussions with the partners of the project.

- Exposed assets:

A 512 m stretch of **mountain trail**, a 364 m stretch of **local road** and a 144 m stretch of **regional road**.

- Protection forests:

A **spruce forest**, with sporadic presence of *Larix decidua* L. at the higher elevations.

- Forest effectiveness against rockfall:

Assets	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Mountain trail	1,319.30	1,421.30	0.42
Local road	-	-	0.75
Regional road	-	-	0.92



- Value of the exposed assets:

Asset	Unitary value immovable [€/m]	Exposed area immovable [mq]	Unitary value movable [€]	Presence probability movable [h]	Presence probability people [h]
Road	N/A	-	20,039	4,2	8,4

FOREST MANAGEMENT

N/A

RESULTS

Overall avoided damage [€]	27,895
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **27,895 €**
- *Unitary Protection Value* **2,273 €/ha**
- *Yearly Protection Value* **71 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The results obtained differ from those in the literature because there is the lack of input data.



9.7 Cevo (IT)

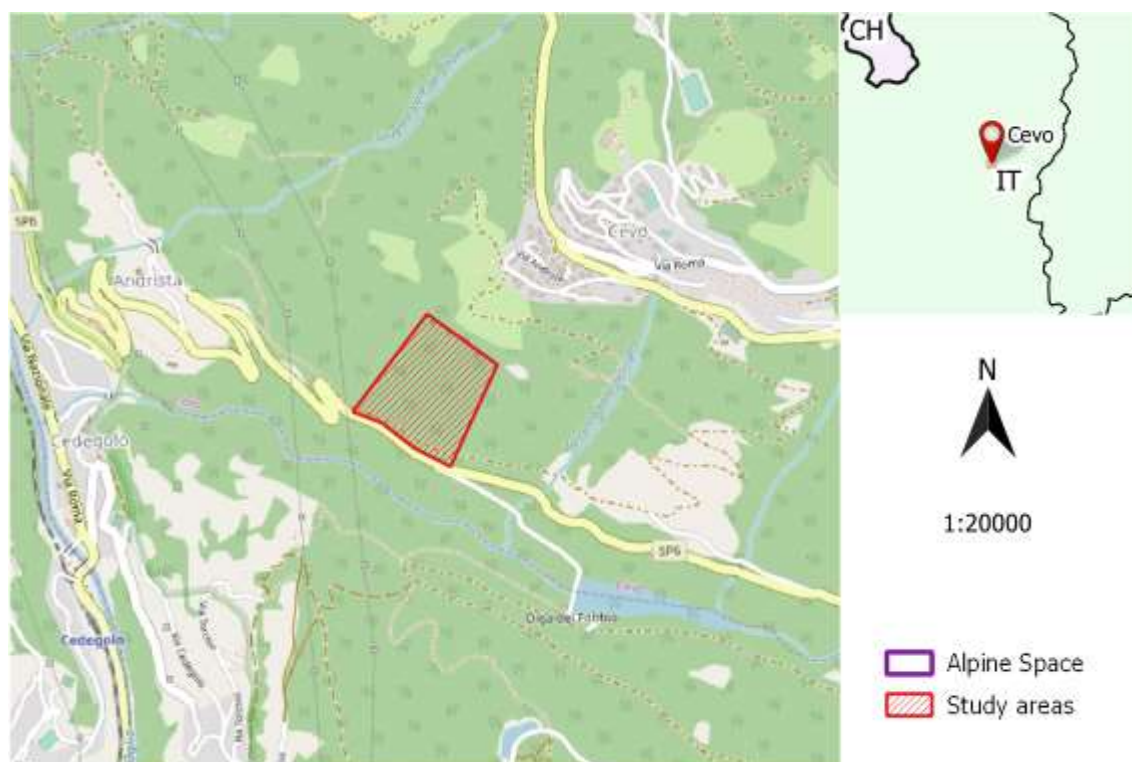


Figure 64: Overview of the Cevo site (central Alps, IT).

Site description

Cevo is located in the Saviore valley, in the province of Brescia (central Alps) and within the boundaries of the Adamello regional park. The area, part of the Southalpine basement, consists of middle to low grade metamorphic units of Variscan age (Edolo schists). These are characterised by foliation processes and isoclinal folds, offering high chances for the origin of rock blocks with discoidal shape. The site has an average slope steepness of 37° and a South-Southeast aspect.

The most widespread forest type in the area is the broadleaves woodland, with main presence of chestnut (*Castanea sativa* Mill.), hop-hornbeam (*Ostrya carpinifolia* Scop.), manna ash (*Fraxinus ornus* L.) and mesophylus oaks (*Quercus pubescens* Willd., *Q. petraea* (Mattuschka) Liebl., *Q. cerris* L.). The most common management of these stands is coppicing with standards, except for the preservation of old production chestnuts where present.

On December 17th, 2017 a rockfall event took place in the Fobbio locality for a total amount of 10 m³ of displaced rocky material that hit the provincial road “SP6” beneath. The position of the blocks related to the event have been located with a high accuracy

DGPS from ERSAF personnel and used lately for the calibration of simulations. In the following spring, a fence net has been built in order to prevent further damages to people and to the road itself.

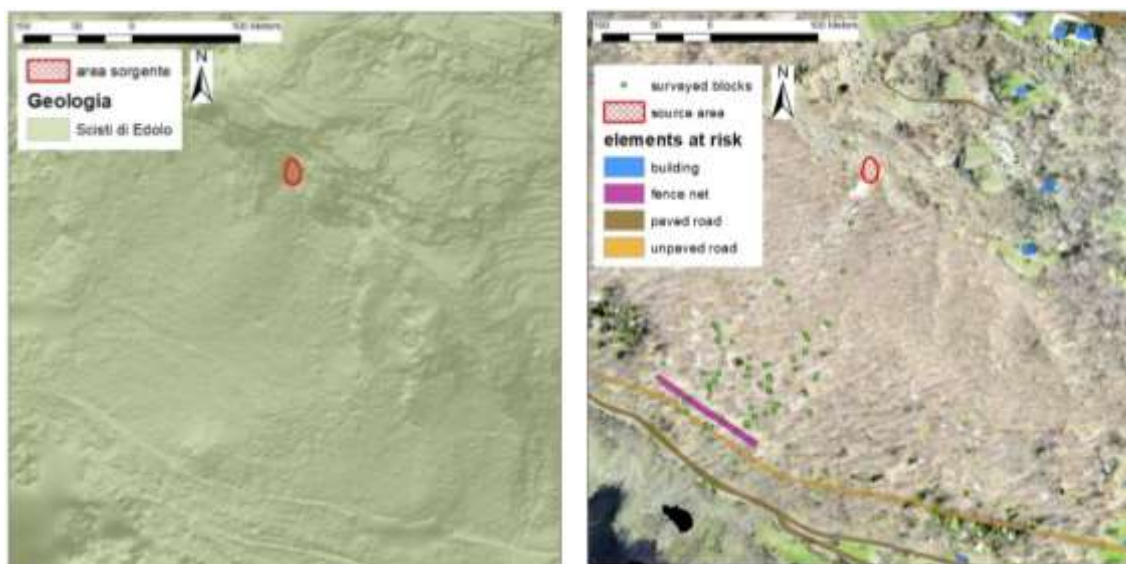


Figure 65: Overview of the site location according to the geological map (left) and the presence of main elements at risk (right).



Figure 66: Presence of large standing deadwood (left) and blocking effect of small stumps (right).

Rockfall modelling

For the Cevo site, different scenarios have been run, including:

- **Sim_rockfall**: simulating the rockfall event with forest at the pre-event density;
- **Sim_net**: simulating the potential rockfall event with forest at post-event density and with the presence of a fence net;
- **Sim_density**: simulating the potential rockfall event with forest at maximum stem density (according to the HY-STONE software);
- **Sim_climax**: simulating the potential rockfall event happening with forest at post-event density and constituted by the strongest species among the available ones (i.e. chestnut);
- **Sim_noForest**: simulating the rockfall event without forest cover.

Sim_density and sim_climax, in particular, were modelled to study which parameter, between stem density and species resistance, could influence more the effectiveness of the stand.

Finally, according to the frequency distribution of rock sizes obtained from HY-STONE, the blocks used for the simulations had a discoidal shape, were 50 cm thick and had minimum, average and maximum axes of 12 cm, 30 cm and 2 m respectively.

The obtained results, summarised in Table 7, show a significant reduction for all the considered parameters (runout distance, number of blocks, kinetic energy and mean velocity) in comparison to the simulation without the effect of the forest (sim_noForest).

The scenario with the overall best results is the sim_climax, capable of reducing the number of block passages to 30% after only 60 metres thanks to the large energy absorption provided by chestnut stems. Nevertheless, for what concerns the simulations, a proper species mixture and stand management averaging the values used for sim_density and sim_climax (closer to the conditions of real stands) could provide an overall minimum efficiency 60%.

Table 7: Results of simulations at the Cevo site.

	Reduction in comparison to <i>sim_noForest</i>			
	Runout distance (average)	Number of passing blocks	Kinetic energy	Mean velocity
Sim_rockfall	71%	70%	53%	63%
Sim_density	74%	73%	61%	63%
Sim_climax	90%	88%	84%	67%



The detailed analysis of all the simulations and additional study cases can be found in the document titled “Servizio di ricerca, sviluppo e valorizzazione delle attività previste dal progetto RockTheAlps” [Italian only].

Economic evaluation

- Selected economic approach:

We choose the **ADM** in order to implement an alternative/different approach to the RCM. In addition to this, in our opinion the ADM could be easily communicated to/understood by citizens and policy makers.

- Selected time period for the evaluation:

25 years, in order to be consistent with the other case studies addressed within the project.

- Exposed assets:

The only exposed asset is the **provincial road n. 6**, from Demo to Fresine, connecting the local villages to the main road (SS42). The road is at risk for a total length of 86 m. Other possible valuable assets in the area (high voltage lines, hydroelectric dam) are not reached/affected by rockfall events simulations.

- Protection forests:

Although information about the forest status is not updated (forest management plan expired in 2014 and not updated), it can be described as an **irregular stand, mixing coppice forests** (chestnut, oak, hornbeam and manna ash), and **high forests** (chestnut and spruce). The total area covered by the protection forest is **3,58 ha**.

- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Provincial road n. 6	0.472	79,655	0,994

The 95° percentile has been calculated from the dimensions of the boulders from previous events, showing a dimension of 1,07 mc. The efficiency simulations have been performed by Milano-Bicocca University team through the proprietary software HY-STONE.

- Value of the exposed assets:

Asset	Unitary value immovable [€/m]	Exposed area immovable [mq]	Unitary value movable [€]	Presence probability movable [/h]	Presence probability people [/h]
Provincial road n. 6	156.99	12	20,039	40	80

- Unitary value immovable:

obtained from Lombardy Region, Regional pricelist of public works - ed. 2019 (i.e., the official pricelist for public works in Lombardy Region), by considering the expected damage a 1,07 mc rock could have on an asphalt road.

- Exposed area immovable:

the area that could be affected by the damage and therefore could need to be repaired.

- Unitary value movable:

obtained from Fleet&Mobility, Mercato Auto Valore - ed. 2017 (i.e., Car Market Value), where the average purchase value of a car in Italy is estimated to be **20,039 €**.

- Presence probability movable:

obtained as an expert-based estimation by interviewing a transport/logistic engineer (Ministero delle Infrastrutture e dei Trasporti, 2018), who compared the road being assessed with average data for mountain roads at the national scale.

- Presence probability people:



We estimated an average of **2 people** (i.e. 1 driver and 1 passenger) per car.

FOREST MANAGEMENT

The area is not managed, and there are **not planned interventions** that could affect forest value.

RESULTS

Overall avoided damage [€]	163,995
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- <i>Monetary Protection Value</i>	163,995 €
- <i>Unitary Protection Value</i>	45,761 €/ha
- <i>Yearly Protection Value</i>	1,429 €/ha/y

CRITICAL ANALYSIS OF RESULTS

Some assumptions were necessary to perform the evaluation exercise:

- every rockfall event has the same dimension distribution;
- the expected rockfall causes the same damage as of similar past events;
- the number of car passages per day on the road equals the average value estimated for similar roads at the national level.

The evaluation exercise returns some important information: the forest appears to provide fundamental protection to prevent damages to the asset, as its efficiency is estimated at 99.4 %. Considering the frequency of rockfall events in the area, the importance of the forest and of its management is unquestionable. While under current conditions there is limited room for increasing efficiency by reactivating active forest management it is possible (based on empirical evidence) that, in the long-term, missing management might lead to forest ageing and worsening of average conditions and this might ultimately turn into lower protection efficiency by the forest.





9.8 Cesana torinese (IT)

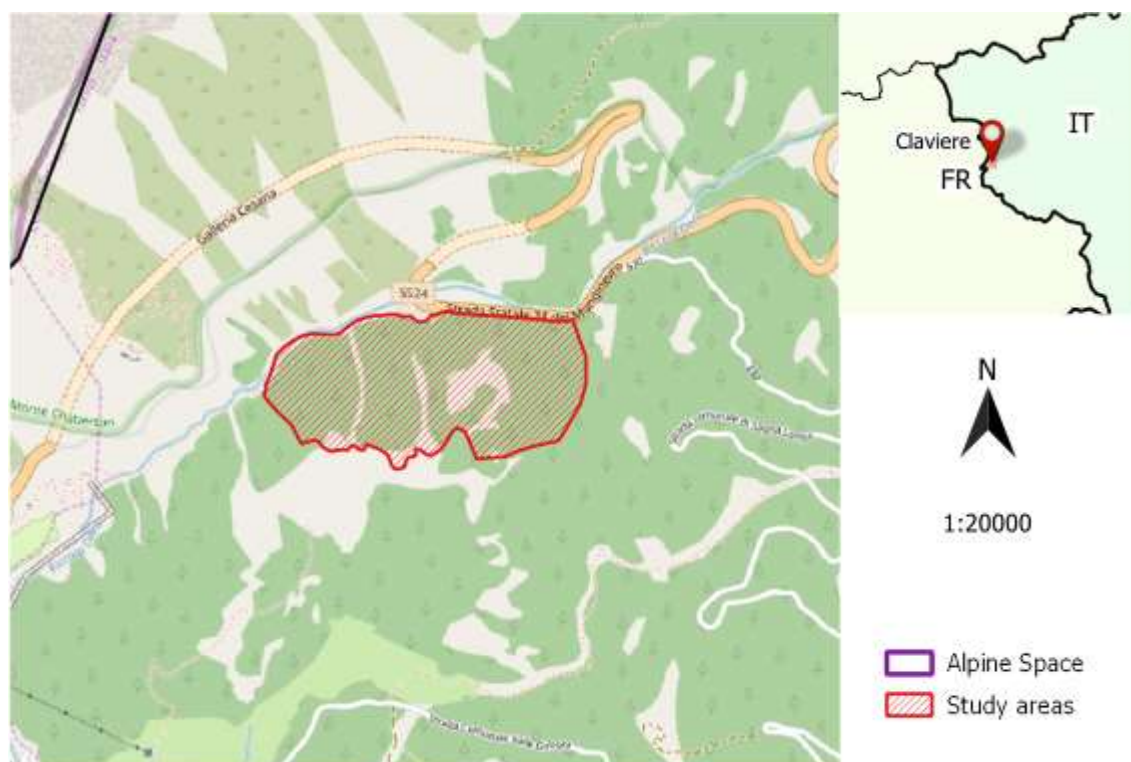


Figure 67: Overview of the Cesana Torinese site (western Alps, IT).

Site description

Cesana torinese is located in the Upper Susa valley, in the province of Turin, near the french border. The rockfall site, called Rocca Clari and located near Strada Statale 24 of Monginevro, is characterized by a short slope which ranges from 1480 to 1640 m.a.s.l. and a length between 150 and 300 m.

The evolution of the slope is essentially due to gravitational phenomena of collapse, for cryoclastism and for avalanches, on a surface of about 8 hectares. The erosive action applied to the lithoid substrate determines the formation of debris deposits, formed by dolomite clasts whose dimensions are determined by the spacing of the joint families and by the impacts with the ground.

The population is constituted by an endalpic silver fir forest, in which the silver fir tends to prevail over the larch in the long term; these two species are accompanied by mountain pine and scots pine in drier situations, then by sporadic spruce. The Forest Management Plan provides a "controlled evolution" that requires constant monitoring of natural hazards against the underlying SS24 of Montgenèvre together with the assessment of the potential contribution of the forest against gravitative events. The exclusive purpose

is improving the protective destination of the forest stands, since it is not possible to manage them for strictly economic purposes.

On June 5th 2011 at 10:20 a.m. there has been a collapse of a limited portion of the north wall of Rocca Clari site. The debris opened a passage in the woodland below between 10 and 30 m wide and 150 m long, and a block of the approximate volume of 10 m³ reached the road beneath.



Figure 68: Removal operations for the boulder fallen on SS24 road during June 2011.

Past forestry interventions pursued the following objectives:

- limit the rolling of rocks near the SS24, through the felling of large, unstable and dying subjects and the placement of the logs transversely to the slope, anchoring them to the stumps;
- opening on the regeneration groups in order to favor a rapid development, such as to increase the number of plants of average diameter, able to hinder the rolling of boulders of medium-small size;
- maintain a high level of biodiversity, preserving larch, mountain pine, scots pine and spruce, in a population in progress towards the pure silver fir forest. This factor improves the resistance of the population towards natural hazards.

Through an assessment of the protective role of the forest population, it has been possible to calibrate local silvicultural interventions able to direct the future evolution towards structures that can better respond to the protection destination assigned to the forest, mainly in the transit, arrest and deposit areas, jointly to the maintenance of a specific good species mixture, which favors biodiversity.

The resulting timber (34 m³ over an area of about 3 ha) was partly left on the felling site and set up at 45° along the slope, with the aim of stopping the rolling of small boulders and limiting surface erosion.



Figure 69: Wooden structures for the reduction of the kinetic energy of rocks along non-forested screes.

After few years from the interventions, the first results related to the protection from smaller boulders are encouraging, showing that the lying logs operated a widespread blocking effect of the rolling rocks.





Figure 70: Blocking effect of lying logs derived from silvicultural interventions after only few years from the felling operations.

1. ECONOMIC EVALUATION

- Selected economic approach:

the **ADM**, the choice fell on this method because there are no rockfall protection nets *in situ* and because the vulnerable element is of some importance.

- Selected time period for the evaluation:

25 years. This value is the result of several discussions with the partners of the project, influenced by the duration of the silvicultural interventions.

- Exposed assets:

the only exposed asset is a 500 m stretch of **road SS24**, very busy and located on the border between Italy and France.

- Protection forests:

a **larch forest** of 120 mc/ha of commission, with an increase of 0.5 mc/ha/year. Carried out a cut in 2007 of about 1.5 ha with a harvest intensity of 25 %, cycle duration of the cuts 25 years.

- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT ORPI forests (95° perc.) [kJ]
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Road SS24	520	530	0.860
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- Value of the exposed assets:

road data obtained from the Piedmont Region pricelist (2019), movable property and value of human life defined according to what reported by the ERSAF/ETIFOR project partners, presence of car from average annual daily traffic card (ANAS, 2017).

Asset	Unitary value immovable [€/m]	Exposed area immovable [m]	Unitary value movable [€]	Presence probability movable [h]	Presence probability people [h]
Road SS24	887.13	0	20,039	300.80	601.60

FOREST MANAGEMENT

There are no forest plans available and the absence of data did not allow ASFORESEE to calculate this item, so the value within it is 0 €.

RESULTS

Overall avoided damage [€]	125,162
Overall discounted stumpage value [€]	0

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **125,162 €**
- *Unitary Protection Value* **20,860 €/ha**
- *Yearly Protection Value* **651 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

The results obtained differ from those in the literature. The main attributable causes are:

- the value of vulnerable elements: in the case studies present in the literature, higher unit values are assumed than those adopted for Cesana Torinese;
- the number of vulnerable elements: in the case study, reference is made only to a stretch of road. In the literature, instead, a greater number of elements at risk are considered.



9.9 Baška grapa (SLO)

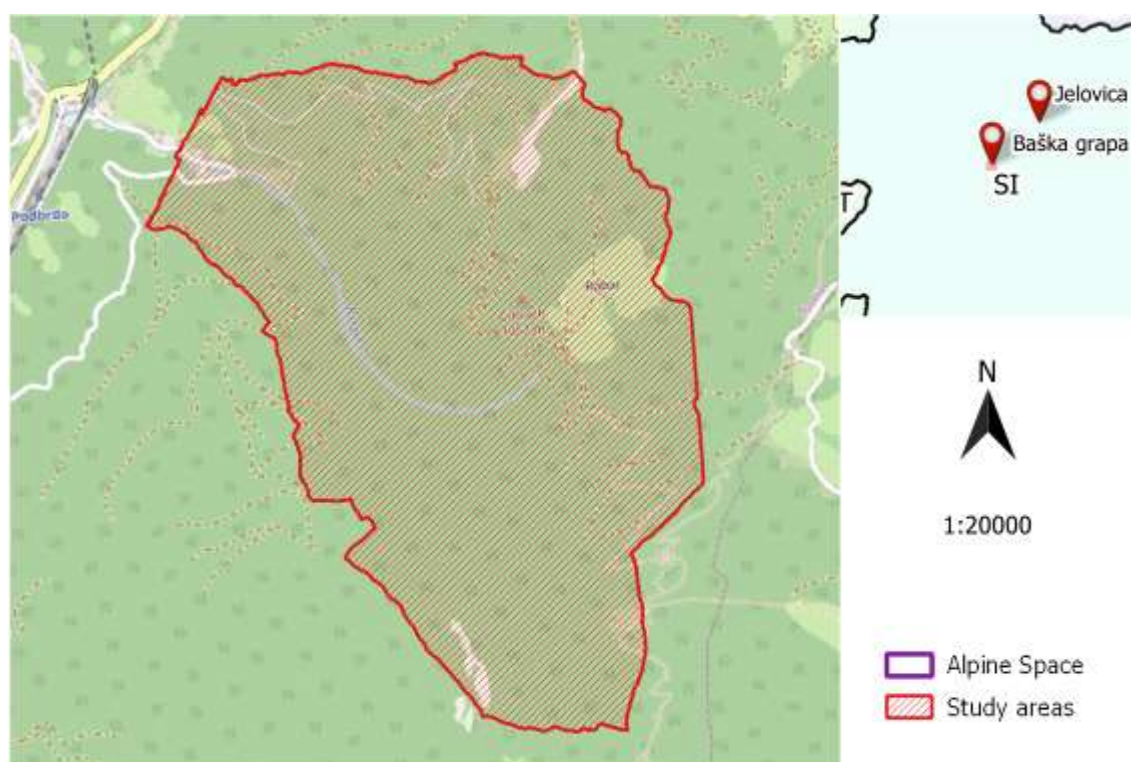


Figure 71: Overview of the Baška grapa site (eastern Alps, SLO).

Site description

Slovenian case study is located in the north-western part of Slovenia more detailed in the upper (north-east) part of the Baška grapa valley, near the town of Podbrdo. Baška grapa is about 30 km long valley of the river Bača, which in the upper part flows in the northeast-southwest direction, and in the south part in the east-west direction. The surrounding mountains do not exceed 2000 m, but the world is very diverse due to the numerous narrow, limestone-carved side gorges.

The study area is 160.8 ha large and is almost entirely forested (95% or 152.5 ha). The rest is agricultural land and some infrastructure. More than half (53%) of the area is occupied by old growth forest stands and an additional 23% with stands in regeneration, where both sum up to a bit more than three quarters. The average stem diameter of 33 cm and growing stock is above nations average at 427 m³/ha y. Average number (modelled) of trees per hectare is 365. European beech dominates with 60% of overall growing stock, followed by Norway spruce (13%), European hop-hornbeam (7%), and other species being represented by less than five percent each. Harvesting rate in a wider area of the Baška grapa forest management unit (just over 13 000 ha, of which 10 473 ha is forested) is set

relatively high (101% of yearly increment) due to large need to establish young growth – more than half of the 686 077 m³ of projected fellings are planned as regeneration cuttings of mature forest stands, which represent almost half of entire forest area. Soto say, age distribution in Baška grapa forest management unit is unbalanced with a serious overrepresentation (45%) of mature forests and a strong lack of young growth (1,3 %).

The bottom part of the area reaches the railway that connects the villages of Bohinjska Bistrica and Most na Soči. Next to it and the study site there is a regional road, one of the few ones connecting Gorenjska region with the upper Primorska region (NW part of Slovenia). The railroad intersects the Bača river seven times during its way through the narrow valley of Baška grapa, running mainly under north-facing slopes while the road seats almost entirely on the opposite side of the valley. Train traffic is rare, while the road is relevant in terms of traffic density with approximately 1000 vehicles passing daily.



Figure 72: The target railway in Baška grapa.

From the detailed digital terrain model of the case study area it is possible to see that the slope faces mainly in the directions north to north-west with two larger gullies having outlets in the south and east, merging close to the central part and then continuing as a larger trench in a north-west direction.



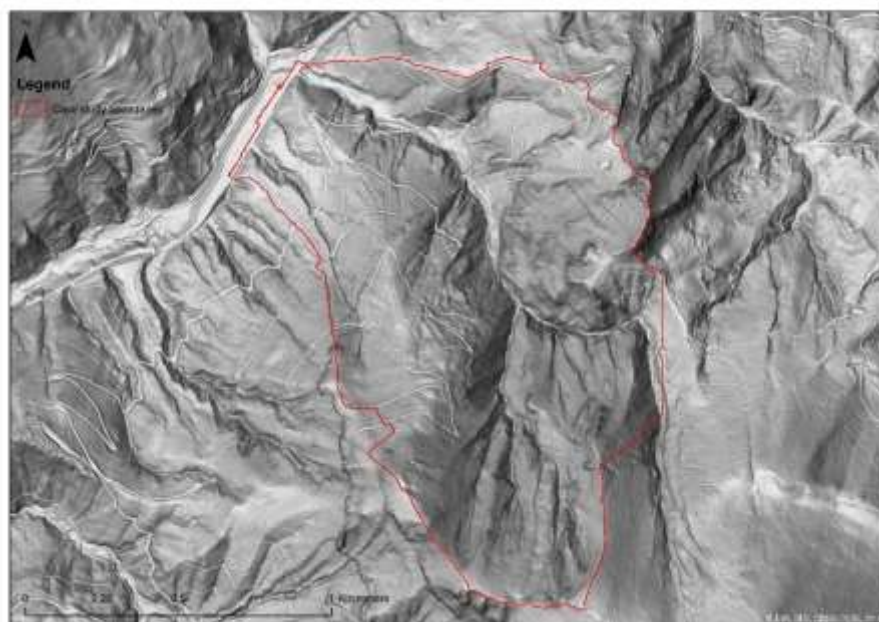


Figure 73: Digital elevation model of the case study area

Due to significant inclination of terrain and geological structure – marl and sandstone with inclusions of limestone –, which is susceptible to erosion, rockfall is quite frequent, posing threat to rail traffic. Several defensive facilities were built in the past, however not on all locations needed. In fact, no protection infrastructure is in place above the railroad in this part of the case study area, thus all protection currently available is provided by the forests uphill. The total length of the railroad bordering the forest area is 430 m.

ECONOMIC EVALUATION

- Selected economic approach:

The **RCM** is adopted because the rockfall nets were installed to protect a railroad, frequently used.

- Selected time period for the evaluation:

10 years. The time horizon fits the one established within system of forest management planning in Slovenia as all management plans have the same period of validity.

- Exposed assets:

The asset which is exposed to rockfall is a **railroad** connecting Bohinjska Bistrica and Most na Soči, but the case study is focused on a specific section stretching through the narrow valley Baška grapa, with steep north to north-west facing steep forested slopes.

- Protection forests:

The forest area under investigation is the first one after the railroad exits the tunnel going under Koblja mountain (Karavanke Alps).

- Forest effectiveness against rockfall:

Asset	Kinetic energy WITH forest (95° perc.) [kJ]	Kinetic energy WITHOUT forests (95° perc.) [kJ]	ORPI
Forest road	4,152	5,744	0.35

- Desired protection level from stakeholders:

The desired level was set on **80 %** indicating relatively **high demand**. Given the ORPI of 0.35, the protection is still not sufficient.

- Score of the protection demand survey:

The score of protection survey **has not been completed** thus only the abovementioned value was used.

FOREST MANAGEMENT

Forests in case study area are managed according to forest management plan (author Slovenian Forestry Service) for forest management unit Baška grapa with a period of validity 2016-2025. A short summary of the plan reveals that forests in this area hold above country's average growing stock of 352 m³/ha, with a below average increment of 6.5 m³/ha y. The latest indicates that the forests are mainly growing on poor soils and in extreme relief conditions. European beech dominates with 60 % of overall growing stock, followed by Norway spruce (13 %), European hop-hornbeam (7 %), and other species being represented by less than five percent each. Harvesting rate is set relatively high (101 % of yearly increment) due to large need to establish young growth – more than half of the 686,077 m³ of projected fellings are planned as regeneration cuttings of mature forest stands, which

represent almost half of entire forest area. Soto say, age distribution in Baška grapa forest management unit is unbalanced with a serious overrepresentation (45 %) of mature forests and a strong lack of young growth (1.3 %). The value of forest management amounts to **240,349 €**.

RESULTS

Overall discounted building cost without forest [€]	-
Overall discounted building cost with forest [€]	-
Overall discounted stumpage value [€]	240,349

In consideration of these results, the overall protection value of the forest stand against the rockfall risk is equal to:

- *Monetary Protection Value* **240,349 €**
- *Unitary Protection Value* **1,495 €/ha**
- *Yearly Protection Value* **137 €/ha/y**

CRITICAL ANALYSIS OF RESULTS

Since kinetic energy reduction due to forest being present is notable, however not sufficient to reduce the need for extensive protection, facilities costs for such infrastructure are high in both cases – with and without forests. The ASFORESEE module of ‘defensive facility’ predict the same protection net characteristics due to SEL kinetic energy exceeding the max absorbable energy of 10,000 kJ (19,902 kJ in case without forest and 14,386 kJ with forest). In this case the discounted stumpage value (the net cost/benefits of forest management) actually increases the value of forests.

Overall, such estimates would be a novelty in case of forest management in Slovenia as economic valuation of protection capacity of forest is not practically implemented except in a few ad-hoc project researches studies. It would enrich information evidence for forest managers to effectively earmark limited resources for supporting such functions of forest stands. Up to now, forest management planning is considering a wide variety of positive



effects of forests on wellbeing in terms of forest function mapping and adapting management accordingly, however criteria upon which this is done are ambiguous and to some extent arbitrary. In majority of cases of forest functions, the system lacks solid data on which designation of a specific forest area to provide for a specific function would be professionally valid. The designation is commonly based on visual assessment of forest stands and environmental circumstances and ignores the true preferences of local people. Economic valuation approach implemented in RockTheAlps integrates the aspect of societal demand for protection via the required level of protection and so guarantees this missing element. It also introduces an approach which is transparent, repetitive and enables sensitivity analysis. The latter enables forest managers to pinpoint the structure of forest stand, which provides protection but can also be optimized in a cost benefit technique.

Future work in this respect would be to investigate possibilities for introducing this approach into forest management in Slovenia. On-going process of renovation of the system of planning might be a suitable opportunity in which the deliverable D.T4.5.1 would for sure be a useful input and a starting point.

9.10 Jelovica (SLO)

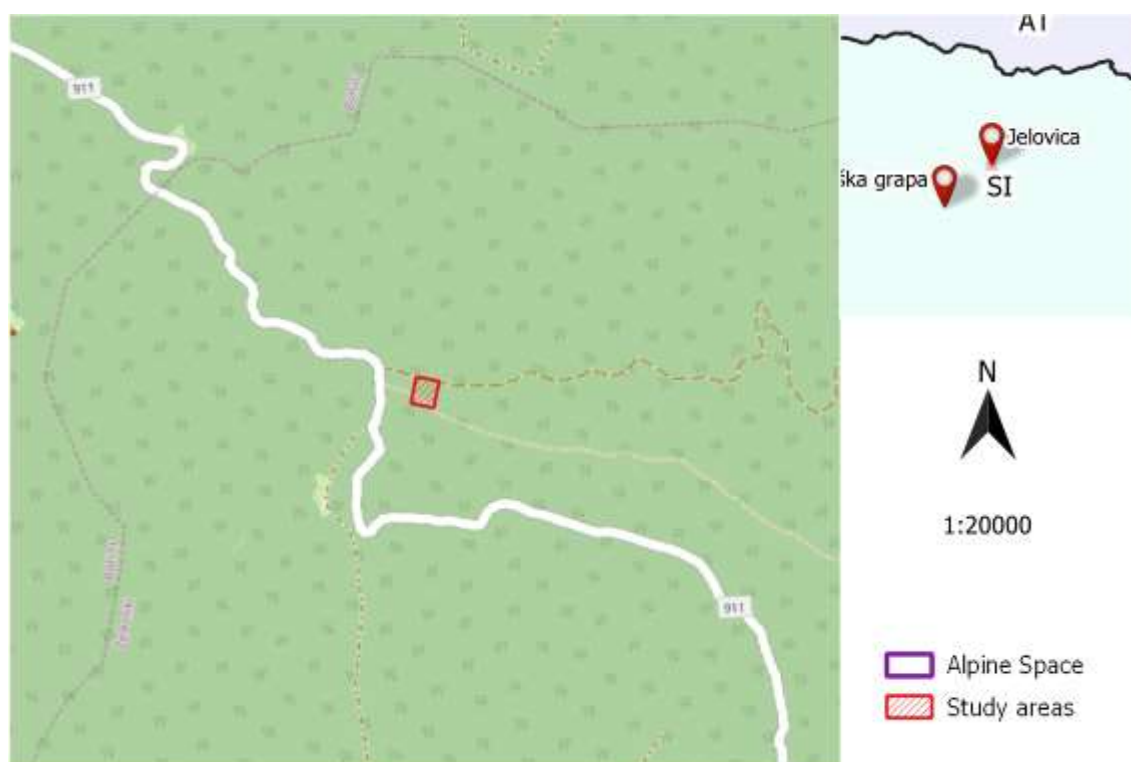


Figure 74: Overview of the Jelovica site (eastern Alps, SLO).

Site description

As a part of activities of ROCKtheALPS project, a field experiment of protection effect of forest against rockfalls was conducted on 9th and 10th of April 2019. The aim of the experiment was to study the response of the adult forest stand on the effect of rockfalls, and determine the kinetic energy of falling rocks along with their bounce heights. The results of the experiment can serve for developing of a process-based 3D model for modelling rockfall trajectories, and will serve as a tool in planning of protection measures against rockfalls in the areas where protection effect of forest is insufficient.

The site chosen for the experiment is located on the plateau Jelovica, in the north-western part of Slovenia, near the settlement Železniki. The area is on steep terrain within a mature protection forests. The stand is mostly represented by three tree species: 65% *Picea abies* (L.) Karst., 30 % *Abies alba* Mill., 4 % *Fagus sylvatica* L., and 1 % other species. Site is located on the elevations between 1010 m and 1170 m with average slope angle of 30°. The terrain is mainly formed from limestone.

For conducting the experiment, a collection of rocks with volumes between half and one cubic meter had to be collected and brought to the site. In order to release the rocks down the slope, an starting point from the road upslope the forest has been used, and rocks were released using an excavator. Before the experiment, the rocks were marked with numbers (Figure 75) and photographed in different dimensions in order to create a 3D model (Figure 76). In this way, it has been possible to determine the shape and the volume of each rock with high accuracy. Before the experiment we also measured the positions of each tree in the experiment plot along with their DBH.



Figure 75: All the rocks have been numbered in order to be recognised during each simulation.

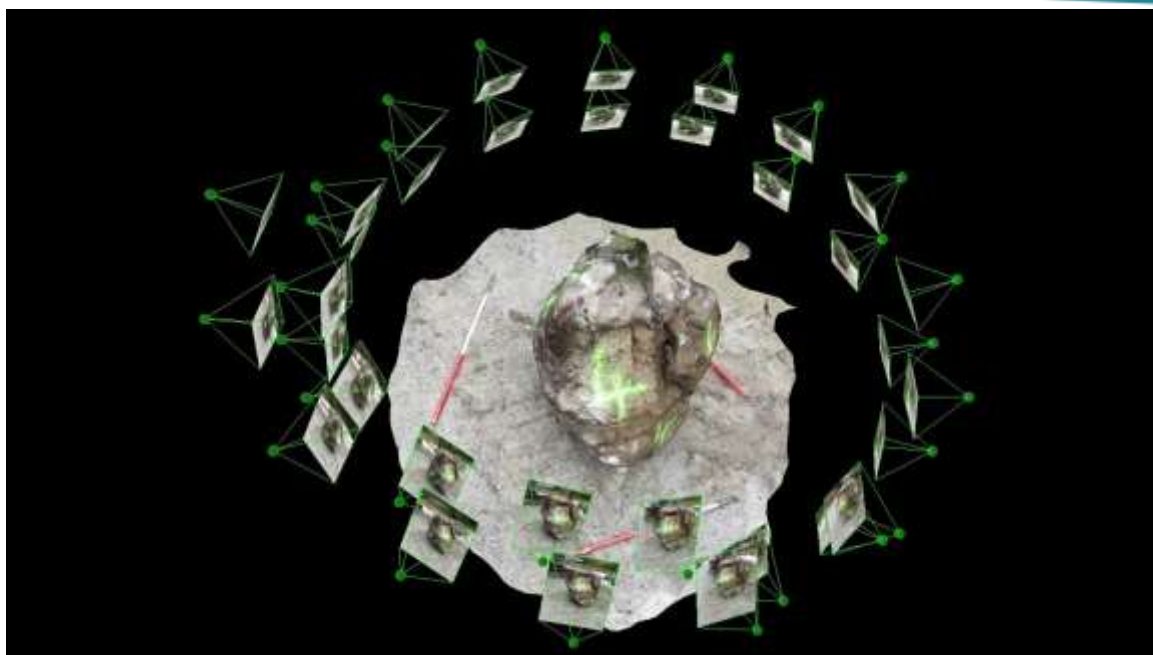


Figure 76: 3D reconstruction of a rock used during the experiment.

Cameras were installed along the experiment slope in order to capture the movement of the rocks during their movement down the slope. They were installed on four different locations, capturing different angles of slope. Data captured with cameras were used for reconstructing the rock trajectories and for calculating their kinetic energies. At the end of the experiment trees were damaged at different areas, mostly the damages were on the bark, some trees lost their tree top or branches, while one tree was completely demolished.



Figure 77: Rock stopped after the impact with a tree.

The research work on the plot will continue also after the experiment, in order to monitor growth and the vitality of the trees that have been damaged due to the rock impacts. For this reason, each tree was equipped with a dendrometer, which measures the yearly increment. On the other side, the vitality of the trees will be monitored as long as the healing process of wounds, the changes in the anatomy of the wood and its hydraulic conductivity. The results will provide new insights into management of the protection forest against rockfalls.



Figure 78: Impacted trees within the study site: they will monitored in the years to come.

