Illustrated evidence on the protective role of forests against rockfalls risks

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Alpine Space Project 462: ROCKTheALPS

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Preamble

Life in the mountains has always been intimately linked to natural problems. Thus, man has always sought to protect his people and property from natural phenomena. To do this, he has settled in areas where there were no known natural hazards, or in areas sheltered by natural obstacles located both between him and natural hazards, or in areas where he has built obstacles to protect him from natural phenomena. Forests are part of the natural ramparts behind which man has always sought shelter. He thus defined the first forests with a protective function.

The majority of the forests in the Alps are located topographically on more or less steep slopes and high altitude zones on which natural phenomena of various kinds (rock falls, landslides, avalanches, etc.) develop. The sectors that are most sensitive to these natural phenomena (roads, housing areas, ski areas, etc.) have been subject to specific civil engineering protection (nets, racks, dikes, etc.). In the other sectors, the silvicultural management of these forest slopes has so far made it possible to maintain the forest and thus limit the consequences of these natural phenomena. Throughout the world, and particularly in the Alpine region, forests are thus considered as natural protection structures offering, depending on the nature and intensity of the risks generated by gravity hazards (rock falls, landslides, erosion and snow avalanches), protection equivalent to that of civil engineering techniques and structures. On slopes where forests are present, the implementation of technical measures for the reduction of natural risks is often cheaper and can be redundant.

However, it must be noted that forest management in mountain areas is nevertheless in decline for various reasons (disappearance of the rural world and its uses, economic difficulties of the wood industry in mountain areas, private land status, etc.). The result is an abandonment of cultivation practices and consequently an ageing of forest stands, with the result that the structure of these stands and their floristic composition are changing. This evolution facilitates the weakening of these stands in the face of climatic hazards (storms, fires, avalanches, etc.) and limits the protective function that these forest stands could play until then. However, very often and unfortunately, this protective role of mountain forests is only highlighted when the forest cover disappears and natural phenomena generating risks are activated or reactivated.

At the same time, the management of natural and semi-natural environments is becoming a major issue in national and international policies. It is based on the notion of sustainable management, multifunctional management, use values and ecosystem services. In this respect, the preservation and enhancement of the role of forests in protecting against natural risks are essential in strategies to protect the inhabitants, users and economic activities of the Alpine territories.
The presence of a risk necessarily implies protective action to guarantee the safety of the threatened issues. Protection can be effective, medium or low. However, whatever its level, it is limited when there are thresholds of effectiveness depending on the importance of the natural phenomenon. It must be borne in mind that, in terms of natural risk, there is no 100% effective means of protection.

Protection against natural risks involves several actions:

- Active protection: we prevent the phenomena from occurring;
- Passive protection: we prevent phenomena from harming;
- Prevention: we display the risk and prevent the implementation of new issues (regulatory zoning).

**Effects of trees/forests on rock propagation**

It is obvious that the presence of trees is an obstacle to the propagation of rock projectiles. Their effectiveness depends on several factors:

- The probability of encountering the projectile with a tree which depends on:
  - the dimensions of the projectile and the tree,
  - the forest density (number of trees per hectare)
  - and the distribution of diameters measured at breast height (DBH).

- The energy dissipation capacity of a tree which depends on:
  - the type of impact (scratched, lateral frontal),
  - its species (deciduous or coniferous),
  - the height of the impact in relation to its total height,
  - the volume and shape of its crown (friction in the air),
  - the quality of its rooting
  - and its state of health.

However, if a tree can have a positive effect, it is also able to have a negative effect by destabilizing the starting areas through leveraging effect (wind action, root growth, preferential infiltration of rainwater). The forester can also generate negative effects through his activities: poorly dimensioned stumps that can have a springboard effect, trunks left on the ground that can act as block traps and therefore time bombs depending on the decomposition speed of the wood, poorly dimensioned forest roads and tracks that can generate a springboard effect.

These various effects have been the subject of numerous studies at the tree, stand and slope scales. At the scale of the tree, the analyses were and are carried out during laboratory or in situ experiments. At the stand and slope scales, the studies are based on field inventories and modelling work using different scenarios.
This document is an illustrated catalogue of evidences on the protective role of forests against rockfalls risks. It organizes in two parts. The first one corresponds to the scale of the tree (photos and film extracts) and the second ones to the scale of the forest stand and the slope (field inventory, modelling). The second part is a selection of the project's study sites.

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**Part 1: some illustrated evidence of the effects of trees, stump, laying trunk and forest road.**

The material used for this part comes mainly from in situ experiments carried out by Irstea and the project consortium. In order to facilitate the reading and understanding of the film extracts, three photos are given for each effect illustrated:

- The first presents and captions the first image of the video extract with the initial position of the projectile.
- The second is a photomontage representing the trajectory of the projectile and its impact on the obstacle studied.
- The third one is actually the second picture but captioned.

Example of illustration of an effect with three photos from a video film made during an experimental campaign in situ.
List of presented effects:

Example of rebound (film extract) without impact with an obstacle: 15m long rebound, with a maximum passage height of 3m, block of 0.8 m³. Page 5-7

Example of a rock stopped by one or more trees. Page 8-11

Example of damage to a tree. Page 12

Curves of the energy dissipation capacity of a tree as a function of its species and DBH, of the position of the impact on the diameter, of the height of the impact in relation to the total height of the tree. Page 13-14

Stopping a projectile by a tree (film clip). The projectile did not reach the limit of the maximum energy dissipation capacity of the impacted stem.

- Example 1. Page 15-17
- Example 2. Page 18-20
- Example 3. Page 21-23
- Example 4. Page 24-26
- Example 5. Page 27-29

Tree broken by a projectile. The projectile reached the limit of the maximum energy dissipation capacity of the impacted stem.

- Example 1. Page 30-32
- Example 1. Page 33-35

Matrix of lateral deviation as a function of the position of the impact on the diameter of a stem. Page 37

Examples of lateral deviation. Page 37-38

Examples of lateral deviation (film extract). Page 39-41

Examples of stopping by coppice clump trees. Page 42

Behaviour of a coppice stem (film extract). Page 43

Behaviour of a coppice clump trees (film extract). Page 44-45

Examples of crosscutting trees and their blocking effect. Page 46

Effect of a well-positioned and dimensioned laying stem. Page 47-49

Springboard effect of a stump (film extract):

- Example 1. Page 50-52
- Example 2. Page 53-55

Springboard effect of a forest track. Page 56-57
Maximal energy dissipated by trees vs DBH

- Maximal energy dissipated by Coniferous trees [kJ]
- Maximal energy dissipated by Broadleaved trees [kJ]
Ratio [%] of maximal Energy dissipated by a tree with a DBH of 20cm and according to the ratio (height impact/total tree height)
Impact and stopping of the boulder on the tree.
Impact and stopping of the boulder on the tree
Boulder trajectory

Impact and stopping of the boulder on the tree
The boulder partially hidden by the tree in the foreground.

Impact on the tree hidden by the one in the foreground.

Greater slope line.
Part 2: some illustrated evidence of protection forest

20 case studies of the project are used for illustrating the protection role played by forests. 12 of them have been also used for the first operational uses of the economic model ASFORESEE (more details are given in the deliverable DL4.51 downloadable via the project website: https://www.alpine-space.eu/projects/rockthealps/en/home). This are the following ones:

<table>
<thead>
<tr>
<th>Name and place</th>
<th>Efficiency of the forest cover (expressed using the indicator ORPI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaysersberg, France</td>
<td>62% to 99%</td>
</tr>
<tr>
<td>Noirefontaine, France</td>
<td>90%</td>
</tr>
<tr>
<td>Auronzo di Cadore, Italy</td>
<td>99%</td>
</tr>
<tr>
<td>San Vito di Cadore, Italy</td>
<td>92 to 99%</td>
</tr>
<tr>
<td>Strailach, Germany</td>
<td>27%</td>
</tr>
<tr>
<td>Podbrdo, Slovenia</td>
<td>35%</td>
</tr>
<tr>
<td>Cesana Torinese, Italy</td>
<td>86%</td>
</tr>
<tr>
<td>Colcuc, Italy</td>
<td>42 to 92</td>
</tr>
<tr>
<td>Cevo, Italy</td>
<td>99%</td>
</tr>
<tr>
<td>Valdidentro, Italy</td>
<td>12%</td>
</tr>
<tr>
<td>Cogolo, Italy</td>
<td>40%</td>
</tr>
<tr>
<td>Seewände, Germany</td>
<td>90%</td>
</tr>
</tbody>
</table>

The other 9 case studies, all located in Austria, have been also used for developing the TORRID tool box: Galtür, Ischgl, Kappl, Gries im Sellrain, Ried im oberinntal, Gries am Brenner, Vals, St Jodok am Brenner, Zirl.
1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Kaysersberg.

Figure 2 - Municipal boundaries of Kaysersberg and localization of the case study.
2. **CASE STUDY 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 upstream 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.

3. **CASE STUDY FEATURES**

The forest boundaries as show in Figure 3 cover 16.45 ha. The exposed asset is the road RD 415. A linear length of about 450 m of road is exposed.

![Figure 3 - Forest boundaries and asset at stake.](image-url)
Figure 4 - Topography obtained from the LIDAR survey.

Figure 5 - Rockfall sources. This side of the hill produces mainly block of a size inferior or equal to 0.5 mc.
4. **Protection EVALUATION**

- 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 6 - Location map of the five topographic profiles used for the analyses.](image)

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.
Using the tool ROCKFOR\textsuperscript{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.

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

Table 1 - Stand characteristics in each of the five representative profiles.
1. GEOGRAPHICAL FRAMEWORK

**Figure 1** - Localization of Noirefontaine.

**Figure 2** - Municipal boundaries of Noirefontaine and localization of the case study.
2. **CASE STUDY DESCRIPTION**

The case study is located near the road RD437, 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 upstream 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 mc and 2.1 mc.

3. **CASE STUDY FEATURES**

![Figure 3 – Case study.](image)
Figure 4 - Areas potentially affected by the rockfall hazard of the case study as a function of the energy line value $\beta$.

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 5 - 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 6** - 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 7 - 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.

4. PROTECTION EVALUATION

- Exposed assets:

The only asset exposed to the rockfall is a portion of the road RD457 (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 8 - 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 mq/ha (average tree diameter of 15 cm and a stem density of 1,019 stem/ha) up to 30 mq/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:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road RD437</td>
<td>800</td>
<td>1,000</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Case study name: Auronzo di Cadore, Italy
Responsible partner: TESAF

1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Auronzo di Cadore.

Figure 7 - Municipal boundaries of Auronzo di Cadore.
2. **CASE STUDY DESCRIPTION**

The selected site is situated in the municipality of Auronzo di Cadore (BL) on the south-eastern face of mount Col di Vezza. The elevation ranges between 1,015 and 1,305 m a.s.l. and it is characterized by a typical Alpine climate, with a mean annual temperature of 7.2° C and an average annual rainfall of 1,212 mm.

The forest in the study site can be differentiated in two main typologies: in the lowest part the main species is *Picea abies* L. classified as a productive stand, while in the upper zone the main species is *Pinus sylvestris* L. and the stand is classified with a protective function.

3. **CASE STUDY FEATURES**

N/A

4. **PROTECTION EVALUATION**

- Exposed assets:

  A **high voltage line** for 460 m and an 800 m stretch of **road SR48**.

- Protection forests:

  A **pine forest** (*Pinus sylvestris* L.) in the upper zone and a **spruce forest** (*Picea abies* L.) in the lowest part classified as a productive stand.

- Forest effectiveness against rockfall:

<table>
<thead>
<tr>
<th>Assets</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>High voltage line</td>
<td>530.4</td>
<td>624.1</td>
<td>0.99</td>
</tr>
<tr>
<td>Road SR48</td>
<td>-</td>
<td>-</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Case study name: San Vito di Cadore, Italy
Responsible partner: TESAF

1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of San Vito di Cadore.
2. CASE STUDY DESCRIPTION

The selected stand starts at an elevation of 1,120 m a.s.l. and it stops where the scree slope starts, at an elevation of 1,350 m a.s.l.. The area has a typical Alpine climate, characterized by cold dry winters and relatively warm and humid summers.

The forest is mainly composed by *Pinus sylvestris* L., with an important presence of *Picea abies* L. at the bottom. The site is defined as “typical mesalpic Scots pine stand” in the upper part, while at the bottom is defined as “mesalpic Scots pine stand”. Furthermore, at the beginning of the scree slope there is a little stand of *Pinus mugo* Turra defined as “mesothermic Stone pine stand”.

3. CASE STUDY FEATURES

N/A

4. PROTECTION EVALUATION

- Exposed assets:

Three stretch of a road are exposed. In particular, a 240 m stretch in the first part, a 450 m stretch in the second part e finally a 540 m stretch in the last part.

- Protection forests:

A pine forest with an important presence of *Picea abies* L. at the bottom.

- Forest effectiveness against rockfall:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>360</td>
<td>399.3</td>
<td>0.92</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>-</td>
<td>0.99</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>-</td>
<td>0.99</td>
</tr>
</tbody>
</table>
1. GEOGRAPHICAL FRAMEWORK

**Figure 1** - Localization of Strailach.
2. CASE STUDY DESCRIPTION

The area of interest is located near the village of Piding, at an altitude of approximately 455 m above sea level, in the south-eastern part of Germany, on the border with Austria, specifically in the Land of Bavaria (47° 46′ N, 12° 55′ E).

Piding hosts a population of about 5,491 inhabitants (as of 30 July 2018) on an area of 17.67 km² (Berchtesgadener Land, 2018). The total area consists of 56.2 % forest (993 ha), 25.7 % agricultural land (454 ha), 12.8 % urban areas (226 ha), 3.3 % other land, e.g. rocks (59 ha) and 2 % water (35 ha).

3. CASE STUDY FEATURES

Figure 3 delimits the boundaries of the protection forest in the regional technical map (3a), the ortophoto (3b) and the DTM (Digital Terrain Model - 3c).

Figure 3 – Case study.
4. PROTECTION EVALUATION

- 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:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest road</td>
<td>527.1</td>
<td>529.1</td>
<td>0.273</td>
</tr>
</tbody>
</table>
1. GEOGRAPHICAL FRAMEWORK

![Figure 1 - A coarse scale geographical representation of a location (red rectangular) of a wider case study area and a finer scale representation of the wider area and actual location of the case study area (green rectangular).](image)

2. CASE STUDY 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 (Figure 1). 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 2,000 m, but the world is very diverse due to the numerous narrows, limestone-carved side gorges. Images below indicate the wider and more detail location of the case study area.

The study area is 160.8 ha large and is almost entirely forested (95 % or 152.5 ha) (Figure 2). 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 m$^3$/ha $\gamma$. Average number (modelled) of trees per hectare is 365.

Figure 2 - A digital ortho-photo image of the case study area.

The bottom part of the area reaches to the railway which connect the village Bohinjska Bistrica on one side and Most na Soči on the other. Train traffic is rare, however mostly used by car shuttle train and occasional cargo and also as public transport (personal trains) (Figure 3). It was built in 1906 and significantly renovated in the 60s, however it is still not electrified, relatively steep in the section between Podbrdo and Grahovo pri Bači and thus expensive to run. The traffic increases significantly in the summertime when ‘historical’ trains runs daily carrying tourists and railroad enthusiasts. It breaches the river of Bača seven
times during its course through the narrow valley of Baška grapa but keeps predominantly under the north-facing slopes while the road runs almost entirely on the opposite side of the valley. Next to the railway a regional road, one of few connecting Gorenjska region with the upper Primorska region (NW part of Slovenia) is also in near proximity of the case study forest area (Figure 4). The road is important in terms of traffic density as well with app. 1,000 vehicles passing daily.

**Figure 3** - The railroad from Bohinjska Bistrica to Most na Soči (north-western part of Slovenia), with a more detailed location of a case study area (red square).

**Figure 4** - A photo of the train rail in Baška grapa.
3. **CASE STUDY FEATURES**

From the detailed digital terrain model, it is possible to see that the slope faces mainly in the directions north to north-west with two larger gullies having outsets in the south and east, merging close to the central part and then continuing as a larger trench in a north-west direction (Figure 5).

![Digital elevation model of the case study area.](image)

**Figure 5** - 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, which poses 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.
Implementation of Rockyfor3D model garnered modelled rockfall sources, which are indicated in red on the image below (Figure 6). Concentration of sources is in the eastern part of the area also due to steeper terrain.

**Figure 6** - Rockfall sources as modelled by Rockyfor3D.

The most distant point of rockfall source is more than 2 km from the railroad uphill, which means that travel lengths of rocks are relatively long in this forest area indicating potentially high protection capacity. There was no empirical field data on either frequency or mass of past rockfall events to calibrate the model, however forest inventory data on forest stands were used:

- mean DBH (forest stand level data on representation of development phases recalculated as an area-weighted average for entire watershed);
- number of trees (by using local yield tables and an equation $N_{trees}=104,449 \times DBH^{-1.595}$; see graph below) (Figure 7);
• percentage of conifers in the growing stock (using forest management inventory data).

Figure 7 - Model estimation of the number of trees per hectare in a watershed based on the average DBH of trees.

4. PROTECTION EVALUATION

• 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 step 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 Kobla mountain (Karavanke Alps).

• Forest effectiveness against rockfall:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest road</td>
<td>4,152</td>
<td>5,744</td>
<td>0.35</td>
</tr>
</tbody>
</table>
1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Cesana Torinese.

Figure 10 - Municipal boundaries of Cesana Torinese.
2. **CASE STUDY DESCRIPTION**

The area of interest is located 3 km from the town of Cesana Torinese, at an altitude from 1,300 to 1,600 m above sea level in Val di Susa, on the border with France (44° 57’ 11” N, 6° 47’ 30” E).

Cesana Torinese hosts a population of about 1,000 inhabitants (as at 31 December 2014) on a territory of 121 km² (Consorzio Forestale Alta Valle Susa 2000; Comune di Cesana Torinese 2014). The total area is made up of 40.2 % of forests (4,861 ha), 36.8 % of meadows and grassland (4,449 ha), 1.6 % of urban areas (infrastructures and buildings) (192 ha) and 21.5 % of other land, e.g. bushes (2,597 ha).

3. **CASE STUDY FEATURES**

Figures 3 and 4 show, respectively, the boundaries of the protection forest (red polygon) and the element to be protected (i.e., road SS24). A dual carriageway road, busy 365 days a year and leading to the French-Italian border.

![Figure 11 – Localization of the case study.](image-url)
4. PROTECTION EVALUATION

- 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:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road SS24</td>
<td>520</td>
<td>530</td>
<td>0.860</td>
</tr>
</tbody>
</table>
Case study name: Colcuc, Italy
Responsible partner: TESAF

1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Colcuc.

Figure 12 - Municipal boundaries of Colle Santa Lucia.
2. **CASE STUDY DESCRIPTION**

The case study is located on Monte Pore, close to Colcuc, municipality of Colle Santa Lucia (BL). The case is on the south western face of the mountain and it has an elevation that varies from 1,360 to 1,710 m a.s.l. The main forest species is *Picea abies* L., with sporadic presence of *Larix decidua* L. at the higher elevations. On the 2nd of April 2004 the site was affected by a massive landslide (around 4,000 mc of material) that defined the site as “active” for rockfall concern. The area is cut at different points along the study site by 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.

For the means of the research a transect has been created on the study site, it is located at 1,490 m a.s.l. and it is 20 m large and 160 m long, parallel to the level curves, it is 25 m downhill respect to the road that pass through the site.

![Localization of the case study (orthophoto).](image)

**Figure 13 – Localization of the case study (orthophoto).**
3. **PROTECTION EVALUATION**

- 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:

<table>
<thead>
<tr>
<th>Assets</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain trail</td>
<td>1,319.30</td>
<td>1,421.30</td>
<td>0.42</td>
</tr>
<tr>
<td>Local road</td>
<td>-</td>
<td>-</td>
<td>0.75</td>
</tr>
<tr>
<td>Regional road</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
</tr>
</tbody>
</table>
1. GEOGRAPHICAL FRAMEWORK

Figure 14 - Localization of Cevo.

Figure 15 - Localization of the case study.
CASE STUDY DESCRIPTION

Cevo case study is in the Adamello Natural Park, within the Province of Brescia, Lombardy Region, between 600 and 950 m a.s.l..

It is a public owned forest area and its management plan is out of date (expired in 2014): the forest is not actively managed now, despite the presence of relatively valuable species as chestnuts groves.

There have been several rockfall events in the past years, the most recent ones have occurred in 2009 and 2017. The main structure at risk is the Provincial road that is located right underneath the site.

2. CASE STUDY FEATURES

Figure 3 shows the elements characterizing the case study: the protection forest (highlighted in grey) has been identified starting from the source area (highlighted in pink) and by considering and buffering the most probable rocks’ paths. This also enlightened the asset to be protected that is the road located below the forest (highlighted in yellow).

![Figure 3 - Source area, protection forest and the asset to be protected (road).](image)

3. PROTECTION EVALUATION

- 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:**

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provincial road n. 6</td>
<td>0.472</td>
<td>79,655</td>
<td>0.994</td>
</tr>
</tbody>
</table>

  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.
1. GEOGRAPHICAL FRAMEWORK

Figure 16 - Localization of Valdidentro.

Figure 17 - Localization of the case study.
2. **CASE STUDY DESCRIPTION**

   Valdidentro case study is located within the Province of Sondrio, Lombardy Region, between 1,360 and 2,400 m a.s.l.

   It is a public owned forest area and its management plan is now out of date. Anyway, the plan didn’t foresee any intervention because, due to the steep slope, the area is recognized as protection forest and therefore left to natural evolution.

   The first simulation (SCENARIO A) underlined that, considering the 95° percentile, the forest has no protection function because of the predicted rock dimension (2,36 mc).

   Therefore, another scenario was developed by reducing the block dimensions and it resulted that when the rock size equals 1 mc the forest is efficient in protecting one of the roads downhill (SCENARIO B).

   The report will address the two above-mentioned scenarios separately.

3. **CASE STUDY FEATURES**

   Figure 3 shows the elements characterizing the case study: the protection forest (bordered with a yellow line) has been identified starting from the source area (highlighted in orange) and by considering and buffering the most probable rocks’ paths. This also enlightened the assets to be protected i.e. as the two roads located below the forest (highlighted in green and blue, respectively).
Figure 3 - Source area, protection forest and the asset to be protected (road).

4. PROTECTION EVALUATION

- Exposed assets:

Exposed assets consist of the two roads standing below the forest, that are road Fior d’Alpe Cancano (total length of the risk-exposed tract: 1,390 m) and via Degola (total length of the risk-exposed tract: 540 m).

- Protection forests:

Although information about the forest status is not updated, it can be described as a low-density pine forest (Pinus sylvestris L. and Pinus mugo Turra), with presence of some screes. The total area covered by the protection forest is 64.88 ha.
• Forest effectiveness against rockfall (SCENARIO A):

<table>
<thead>
<tr>
<th>Assets</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Fior d’Alpe</td>
<td>3.47</td>
<td>2.59</td>
<td>-0.337</td>
</tr>
<tr>
<td>Cancano</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Via Degola</td>
<td>0.65</td>
<td>0.57</td>
<td>-0.135</td>
</tr>
</tbody>
</table>

The 95° percentile has been calculated from the dimensions of the boulders from previous events, showing a dimension of 2.36 mc. The efficiency simulations have been performed by Milano-Bicocca University team through the proprietary software HY-STONE. Based on simulation outcomes the forest apparently has a negative impact on the energy of the block, accelerating it. This is probably due to the size of the block that restricts the efficiency of the forest at the point that the behaviour of the latter does not perform well in the modelling software.

• Forest effectiveness against rockfall (SCENARIO B):

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (1 mc) [kJ]</th>
<th>Kinetic energy WITHOUT forests (1 mc) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Via Degola</td>
<td>0.324</td>
<td>0.367</td>
<td>0.12</td>
</tr>
</tbody>
</table>

The table represents the results of the simulation with a 1 mc volume boulder. The only asset where an effect is shown is B.
1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Cogolo.

Figure 2 - Localization of the case study.
2. CASE STUDY DESCRIPTION

Forest on a deep hillslope in a small valley called “Val dela Mare”, near Cogolo village. The forest is composed from *Pinus cembra* L. and *Larix decidua* Miller where the latter represent 30% of the forest plants. In the bottom of the forested slope, there is a tourist and leisure area that is used several times during the summertime. In addition to this area, a road passes throw the forest and it is used for Malga Mare restaurant and by workers of a hydroelectric power plant. In the upper part of the forest area and the road, there are several cliffs where rockfall events are generated. Due to the morphology of the slope, the distribution of the rockfall phenomena is different in the area with a heterogeneous spread of rock stack zones and forest stands.

3. CASE STUDY FEATURES

![Figure 3 - Case study (red polygon) and protection forest (blue polygon) in different forms: Regional Technical Paper (a); DEM (b); ortophoto (c).](image)

4. PROTECTION EVALUATION

- Exposed assets:

  It’s a part of the **road** that passes throw 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:**

The surface of the 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:**

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>1,986</td>
<td>2,048</td>
<td>0.40</td>
</tr>
</tbody>
</table>
1. GEOGRAPHICAL FRAMEWORK

Figure 1 - Localization of Seewände.

Figure 18 - Municipal boundaries of Oberstdorf.

2. CASE STUDY DESCRIPTION

N/A
CASE STUDY FEATURES

Figure 3 delimits the boundaries of the protection forest in the regional technical map (3a), the ortophoto (3b) and the DTM (Digital Terrain Model - 3c).

3. PROTECTION EVALUATION

- Exposed assets:

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

- Protection forest:

Figure 3 – Overview of the potential protection forest/Norway spruce functioning as rockfall protection
Figure 4 – Marks of rockfall events on the stem of a Norway spruce/Vertical section through the forest surveyed by terrestrial laser scanning.

- Forest effectiveness against rockfall:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Kinetic energy WITH forest (95° perc.) [kJ]</th>
<th>Kinetic energy WITHOUT forests (95° perc.) [kJ]</th>
<th>ORPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>59</td>
<td>87</td>
<td>0.90</td>
</tr>
</tbody>
</table>
2 Detailed examples of the evaluation of the efficiency of forest against rockfalls risks using a 3d model
VAL DE LA MARE, COGOLO, TRENTO PROVINCE, ITALY

Site description

The two case studies are forests on steep hill slopes, in a small valley called “Val dela Mare”, inside Stelvio national Park in the north-western part of 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 altitude is quite high (1730-2320 m above sea level), presenting a typical high mountain environment of coniferous forest under the treeline and shrubs, grasslands and rock hills above.

Forest stands in the sub-area are uneven-aged, composed by Swiss pine (Pinus cembra L.) and European larch (Larix decidua Miller).

Test area Prabon is a forest protecting several road sectors, while the forest in test area Pontevecchio protects a rural building used in summer for livestock, selling of milk based products and bed & breakfast.
PONTEVECCHIO FOREST

The study area is about 80 ha. Rocks fall frequently from the upper sectors of the area. In June 2018 a very significant rockfall took place, and the boulder path and stopping point are easy to recognise along the forest sectors, as well the impact signs and damages on tree stems and on the soil.

Forest stands are mainly uneven-aged, composed by Swiss pine (*Pinus cembra* L.) and European larch (*Larix decidua* Miller), with different average DBH, height and forest density as follow:

<table>
<thead>
<tr>
<th>Forest stand (ID nr.)</th>
<th>Number of trees/ha</th>
<th>Mean DBH [cm]</th>
<th>% of conifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>653</td>
<td>33</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>449</td>
<td>37</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>224</td>
<td>34</td>
<td>82</td>
</tr>
<tr>
<td>14</td>
<td>245</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>18</td>
<td>327</td>
<td>32</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>490</td>
<td>33</td>
<td>92</td>
</tr>
<tr>
<td>23</td>
<td>265</td>
<td>47</td>
<td>100</td>
</tr>
<tr>
<td>24</td>
<td>490</td>
<td>33</td>
<td>100</td>
</tr>
<tr>
<td>26</td>
<td>245</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>27</td>
<td>245</td>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>28</td>
<td>224</td>
<td>34</td>
<td>82</td>
</tr>
<tr>
<td>30</td>
<td>551</td>
<td>34</td>
<td>100</td>
</tr>
</tbody>
</table>

A rapid simulation with Rockyfor 3D shows the possible trajectories of rocks from the upper release areas to the lower areas and the building.
Detailed Rockyfor 3D simulations were conducted by inputting field surveyed parameters (block diameters, type of soil, forest parameters etc.), to calculate:

- the % of rocks stopped by the forest at 3 different transect level of the hill;
- the % of cumulative kinetic energy of rocks dissipated by the forest

At the upper level ①
- 25% of the total blocks are stopped by the trees
- 24% of their cumulative kinetic energy is dissipated by the forest

At the intermediate level ②
- 38% of the total blocks are stopped by the trees
- 31% of their cumulative kinetic energy is dissipated by the forest

At the lower level ③
- 68% of the total blocks are stopped by the trees
- 65% of their cumulative kinetic energy is dissipated by the forest
The case study focuses 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. The morphology of the slope is heterogeneous as well as the distribution of rock stack zones, forest stands with different density and open grasslands.

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 quick simulation in Rockyfor 3D, which shows the trajectories of single rocks potentially reaching the road sector.

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).
Forest parameters of forest stands are:

<table>
<thead>
<tr>
<th>Forest stand (ID nr.)</th>
<th>Number of trees/ha</th>
<th>Mean DBH [cm]</th>
<th>% of conifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>939</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>420</td>
<td>39</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>286</td>
<td>32</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>529</td>
<td>35</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>939</td>
<td>27</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>204</td>
<td>47</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>286</td>
<td>38</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>251</td>
<td>54</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>139</td>
<td>61</td>
<td>100</td>
</tr>
</tbody>
</table>

Rockfall simulations with and without forest were conducted using Rockyfor 3D, in order to compare number of block passages stopped and kinetic energy dissipated by the actual forest cover. As for Pontevecchio, the specific efficiency of the forest stand above the selected road sector was defined by setting virtual nets on the sector and calculating the ORPI index (which expresses the total cumulative kinetic energy developed) with and without forest. The simulation showed an efficiency of Prabon forest of 40% in terms of kinetic energy:

At the level of the selected road sector (yellow in picture),

- 48% of the total blocks passages are stopped by the trees
- 40% of their cumulative kinetic energy is dissipated by the forest.

*Simulation of number of rockfall in absence of forest (left) and with the actual forest stands (right) in Prabon area.*
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.
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.

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

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 mesophyllus 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 m$^3$ 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.
Overview of the site location according to the geological map (left) and the presence of main elements at risk (right).

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 the table below, 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%.

### Results of simulations at the Cevo site.

<table>
<thead>
<tr>
<th></th>
<th>Reduction in comparison to <em>sim_noForest</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim_rockfall</td>
<td>Runout distance (average)  71%</td>
</tr>
<tr>
<td></td>
<td>Number of passing blocks 70%</td>
</tr>
<tr>
<td></td>
<td>Kinetic energy 53%</td>
</tr>
<tr>
<td></td>
<td>Mean velocity 63%</td>
</tr>
<tr>
<td>Sim_density</td>
<td>Runout distance (average)  74%</td>
</tr>
<tr>
<td></td>
<td>Number of passing blocks 73%</td>
</tr>
<tr>
<td></td>
<td>Kinetic energy 61%</td>
</tr>
<tr>
<td></td>
<td>Mean velocity 63%</td>
</tr>
<tr>
<td>Sim_climax</td>
<td>Runout distance (average)  90%</td>
</tr>
<tr>
<td></td>
<td>Number of passing blocks 88%</td>
</tr>
<tr>
<td></td>
<td>Kinetic energy 84%</td>
</tr>
<tr>
<td></td>
<td>Mean velocity 67%</td>
</tr>
</tbody>
</table>
Evidence of forest protective effect in Austria

A total of 58% of the Austrian territory is designated as intensive zones of protection against natural hazards in the Alps. Forests as protection against natural hazards play a decisive role in this context: about 1/4 of the forested areas have a direct object protection function against gravitational processes. As calculated in RockTheAlps, about 10% of the forested area have a direct object protection function against rockfalls, fig.1 shows the distribution over the Austrian provinces.

![Protection forest in Austria's provinces](image)

**Fig. 1: Forests with object protection function in Austria**

Therefore a lot of field studies has been carried out in order a) to demonstrate the efficiency of protection forests against rockfalls and b) to calculate the efficiency with the new TORRID tool. Both activities will be shortly outlined here.

**Demonstration of protection forest efficiency against rockfalls by field survey**

In the model communities of Galtür, Ischgl, Sellrain and Gries im Sellrain (all in the most endangered province of Tirol) field surveys have been carried out, on the one hand to compare the existing forest-related map and information material with the current conditions on site and on the other hand, to validate the results of the modelling carried out.
In order to demonstrate the efficiency also different forest types has been systematically selected:

- **Spruce forest**: spruce dominant, larch and subdominant arolla pine, rowan and birch
- **Larch-spruce forest**: spruce and larch dominant, green alder and arolla pine
- **Larch forest**: Larch dominant, spruce mixed in
- **Mountain pine - green alder - birch - hardwood bush forest**: only birch and green alder included
- **Pine-oak-ash-lime forest**: pines dominant

**Forest stand sampling**

Angle counting\(^1\) tests were carried out at each recording point in combination with four fixed test surfaces. This allowed the inclusion of stems with a smaller diameter than the selected clip threshold (12 cm).

---

\(^1\) The angle counting sample is a sampling procedure of the forest inventory, which determines the number (N) of trees within a virtual sample circle and is carried out with the help of the mirror relascope of Bitterlich (1948). Fixed plot areas are areas with predetermined dimensions on which the vegetation is recorded.
Fig. 3: Staking out a fixed sample area in Gries im Sellrain

The forest-specific parameters were documented at selected transect sampling points of the forest surveys:

- Tree species [-]
- Diameter of the breast height (BHD) [m]
- Tree height [m]
- Status [-]
- Habitus [-]

The status was determined by a visual quality assessment based on the status classification shown in Figure 4. These recorded parameters made it possible to determine the floor area (m²/ha), log numbers (N/ha) and timber stock (m³/ha).

Fig. 4: Status of woody plants. (Perzl, 2018) modified from Maser et al (1979) and Backhouse & Lousier (1991).

**Sampling of damages on stems**

In addition to the forest-specific measurements, information on damages caused by gravitative processes were documented along each transect. The recording of rockfall
Damage was not limited to the sample areas but was recorded along the entire transect. When documenting impact wounds on single trees, it was important to differentiate between wounds caused by alpine processes and wounds of other origins, although a distinction to wounds caused by anthropogenic influence was not always clearly possible. Gsteiger (1989) describes general indications for the differentiation of rock fall wounds from structures of questionable origin.

Fig. 5: Stopped stones and stone chips in Gries im Sellrain (left) and Galtür (right) show the effectiveness of forest against rockfalls

When damages were recorded, the following information was documented on the wounds of the tree trunks:

- Length, width and height of the wound
- Disposition of the wound
- Age of the wound
- Deposit areas
- Pest infestation

The age of the wound was only mentioned in the form of a division of old and young. Young was defined by freshly exposed wood, sparse overgrowth and light, fresh resin. (Eichenberger et al., 2017)

### Study site Galtür

<table>
<thead>
<tr>
<th>Galtür</th>
<th>Nr. transects</th>
<th>Nr. stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce forest</td>
<td>4 (2)</td>
<td>7</td>
</tr>
<tr>
<td>Larch and spruce forest</td>
<td>2 (1)</td>
<td>14</td>
</tr>
<tr>
<td>Larch forest</td>
<td>3 (1)</td>
<td>2</td>
</tr>
<tr>
<td>Mountain pine - green alder - birch - hardwood bush forest</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Fig. 6: Example Galtür (Jamtal), the release area is the central wall above the forest (left image); huge blocks are stopped by the forest

Study site Ischgl

Fig. 7: Release area in Ischgl and adjacent track

<table>
<thead>
<tr>
<th>Ischgl</th>
<th>Nr. transects</th>
<th>Nr. stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce forest</td>
<td>4 (1)</td>
<td>10</td>
</tr>
</tbody>
</table>
Study site Kappl

<table>
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<tr>
<th></th>
<th>Nr. transects</th>
<th>Nr. stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce forest</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Study site Gries/ Sellrain

<table>
<thead>
<tr>
<th></th>
<th>Nr. transects</th>
<th>Nr. stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce forest</td>
<td>7 (2)</td>
<td>12</td>
</tr>
</tbody>
</table>

Fig. 8: Release area in Kappl

Fig. 10: Release area and adjacent track Narötz, Gries i.S.
### Summary of transects per forest type

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Nr. transects</th>
<th>Nr. stones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spruce forest</td>
<td>22 (9)</td>
<td>42</td>
</tr>
<tr>
<td>Larch and spruce forest</td>
<td>3 (2)</td>
<td>15</td>
</tr>
<tr>
<td>Larch forest</td>
<td>3 (1)</td>
<td>2</td>
</tr>
<tr>
<td>Pine-oak-ash-lime forest</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>MountPine - green alder - birch - bush forest</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td><strong>30</strong></td>
<td><strong>67</strong></td>
</tr>
</tbody>
</table>

### Calculation of protection efficiency with the TORRID toolbox

The Torrid toolbox was developed in order to calculate the reduced run-out and subsequently the reduced risk described in the Risk Reduction Index. The TORRID Toolbox itself is described in the deliverables D.T.2.(1-4). Here, the data driven modelling results of TORRID and ROCK-EU are presented, as used by practitioners for demonstrating the protective effect of forests.

In addition to the above mentioned field studies, a special TORRID rockfalls sampling course has been executed. The field work for TORRID was conducted in the summer of 2018. Rockfall events with a minimum dimension of 50 centimeters were recorded and a variety of biotic and abiotic parameters were collected.

Before the field work, preprocessing of the of the rockfall event and study sites included:

- Preliminary orthophoto-mapping of the rockfall trajectory
• Segmentation of the rockfalls trajectory into units of homogeneity orthophotos and other available data

• Determination of the position of the center points for the angle count sampling, to ensure an efficient work flow

• If possible, a preliminary on-site inspection of the rockfall trajectory and optional adjustment of the advance work. (Perzl et al., 2018)

In figure 10 a transect from the source area to the deposition zone is shown with yellow markings indicating the position of the sample plots.

![Figure 10: Exemplary illustration of the collected data along rock paths](image)

Fig. 11: Exemplary illustration of the collected data along rock paths

Abiotic parameters described the path of each rock from the source area to the deposition zone. Each rockfalls path was divided into units of homogeneity, isolating sections with different land cover types. Each unit length and height difference were measured.
- **Basal area [m²/ha]:** Using the angle count sampling method (ACS) (Bitterlich, 1984) or fixed area plots, the tree diameters at breast height (DBH) were gained, so the basal area could be calculated.

- **Stand density [N/ha]:** In course of the ACS also the stand density was determined, to get the number of woody plants per ha regardless of plant size.

- **Species composition:** The composition of tree or woody vegetation species was collected, but due to the vast amount of different tree species the input parameters for the species composition was reduced to the percentage of coniferous and broadleaved proportions of the forest.

- **Proportion of shrub forest:** The percentage of shrub vegetation in a unit was collected, to determine the effect of high-density forests with low DBH values.

### Results of TORRID field survey

<table>
<thead>
<tr>
<th>Length</th>
<th>Height</th>
<th>Description</th>
<th>Basal area</th>
<th>Stand density</th>
<th>Species composition</th>
<th>High forest</th>
<th>Shrub forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>[m]</td>
<td>[m]</td>
<td>[m²/ha]</td>
<td>[N/ha]</td>
<td>[%]</td>
<td>Picea</td>
<td>Larix</td>
<td>Fagus</td>
</tr>
<tr>
<td>50</td>
<td>18.93</td>
<td>Spruce forest</td>
<td>50</td>
<td>1280</td>
<td>0,9</td>
<td>0,1</td>
<td>-</td>
</tr>
<tr>
<td>35</td>
<td>13.59</td>
<td>Larix forest</td>
<td>27</td>
<td>1465</td>
<td>0,06</td>
<td>0,94</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>16.07</td>
<td>Sparse fagus forest</td>
<td>13</td>
<td>150</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>175</td>
<td>110.28</td>
<td>Scree</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>119.49</td>
<td>Rock cliff</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

TORRID provides three different forest groups. The 698 rockfall profiles were classified in one of the forest groups, coniferous forest (A), mixed forest (B) or broadleaved forest (C). The threshold for mixed forests was defined at 20 percent.
- Forest group A – coniferous forest stand includes 41% of the data
- Forest group B – mixed forest stand includes 29% of the data
- Forest group C – broadleaved forest stand includes 30% of the data

Figure 11 shows a comparison of the survival curves of the three forest groups.

**Survival curves of TORRID for forest groups A, B and C**

![Survival curves of TORRID](image)

Fig. 12: Survival curves of TORRID

Figure 12 shows the percentage of passing rocks of a defined forest group along the normalized potential runout distance in form of a survival curve including confidence intervals and indicating the efficiency of a forest to reduce the run-out.

Even though the coniferous forest (A), visualized in yellow, shows the steepest declination in the beginning, it presents as an intermediate curve, whereas the mixed forest group (B), visualized in blue, illustrates as the overall fastest declining survival curve by reaching nearly 0% of passing rocks before 50% of the normalized potential runout distance is reached. Forest C, the broadleaved forest group, represented in grey, shows the flattest survival curve.

Details are outlined in the methodology chapter of the TORRID deliverable.
Risk reduction curves TORRID

Fig. 13: Risk reduction curves of TORRID light in forest group A, B and C

Comparison of the modelled and recorded stock losses

For the transferability of the project results, the calculation of protective effects, to other areas is the relationship between modelled hazard process areas - for which an increased density of damage in the stock is expected - and the observed damage. In order to be able to make this comparison of the modelling results with the actual state, to determine the efficiency directly, photographs were taken in areas with different hazard potential levels. The field surveys not only included forest sites with high modelled process activity, but also sites where the modelling showed no or only low hazard potential.

The aim of this comparison is to establish the quantitative relationship between the hazard potential according to the modelling and the frequency of impact wounds. Since the length of the transect has an influence on the number of recorded rock fall wounds, the number of wounds was related to the forested length of the transect. This gives a ratio of 0 to 0.4 between simulated hazard potential and observed damage. It should be noted that, in addition to the length of the transect, other factors (e.g. stem density, mean DBH or block diameter) also have an influence on the number of impact wounds. However, this could not be explained in detail in these analyses.
The comparison shows that the damage factor is considerably higher in areas with high and medium hazard potential. Although the correlation can still be improved quantitatively, the correlation is clearly recognizable as a trend. In order to keep evaluation distortions as low as possible, those areas in the terrain were specifically selected in which a high or medium hazard potential was induced by the simulation, but where no rockfall events have been documented to date. In zones with a low hazard potential the number of wounds also decreases significantly; no wounds were found in areas without a proven hazard potential.

As an example, Figure 14 and Figure 15 show areas with high calculated hazard potential and the rockfall protection effects found during field surveys.

Fig. 14: Illustration of the relationship between the identified hazard potential and the frequency of rock fall injuries.

Fig. 16: Extract from the rockfalls and hazard potential map of RTA in Gries im Sellrain (left) and documented rockfalls event (right)