Balancing tradition and technology to sustain rockfall-protection forests in the Alps

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Abstract
It is still uncertain what a mountain forest should look like to provide optimal protection against rockfall. Knowledge is limited due to the slow reaction of mountain forests to the rapid environmental and socio-economic changes that have occurred in the Alps over the past 100 years. Fortunately, research has progressed and an enormous amount of experiential knowledge has been gained, providing a basis for finding a balance between maintaining traditional practices and implementing new technology. This paper identifies an approach that could be used as a rough framework for managing and sustaining forests with a protective function in the Alps. Three main points are discussed: 1) evaluating traditional 'good practices' and mistakes, 2) evaluating new technologies, especially those in the field of rockfall-protection forests, and 3) merging the best of the two worlds. The evaluation of traditional ways of managing protection forests shows that the 'do nothing approach' and earlier trends in spatial planning should be avoided. In the past, people were more inclined to believe that risks were always present in mountain areas. Aware of the protective functions of forests, they did not touch forests in areas where natural hazards posed risks to settlements. Protection forests were therefore not subject to harvesting. In addition, construction did not take place in areas where natural hazards posed high risks. A review of the technologies developed during recent decades shows that we can now assess quantitatively how well different mountain forests perform in providing protection against rockfall. We show how new research tools can help in assessing the required silvicultural actions to optimise the protective function of forests.

Keywords: protection forest, traditional protection forest management, rockfall-protection forests

1 Introduction

Many livelihoods in the Alps rely heavily on mountain forests for protection against rockfall and snow avalanches. This is identified in the first paragraph of the Mountain Forest Protocol of the Alpine Convention (European Communities 1996): "mountain forests … provide the most effective, the least expensive and the most aesthetic protection against natural hazards." In Austria and Switzerland alone, approximately 50 million Euros are spent yearly to maintain or improve the protection provided by mountain forests (European Observatory of Mountain Forests 2000; Swiss Federal Statistical Office 2002). Increasingly, the protective functions of mountain forests need to be combined with other functions and uses. This is difficult as foresters and forest researchers are still determining the characteristics of a forest that provide optimal protection. Knowledge is limited due to the slow reaction of natural forests to the rapid environmental and socio-economic changes that have occurred in the Alps over the past 100 years. Fortunately, there has been considerable progress in research on protection forests. In parallel, practitioners have gained experience in managing protection forests. The combination of this knowledge and experience provides a basis for balancing tradition and technology. The aim of this paper is to review this information and use it to develop a framework for managing and sustaining forests with a protective function in the Alps. Three main points are discussed:

1. evaluating traditional 'good practices' as well as past mistakes
2. evaluating new technologies in rockfall-protection forest studies
3. merging the best of the two worlds

This paper concentrates on these three points, particularly as they relate to rockfall.

2 Protection forests in the Alps

In the European Alps, mountain forests and the protection they provide have a long and distinguished history. However, in the last few decades, forest management has shifted its focus from timber management to multiple use and forest ecosystem management (Buttoud 2000; Führer 2000). During this transition, there has been an increasing awareness of the need to manage the multiple functions of mountain forests. Traditionally, mountain forests have been exploited for their timber and non-timber products, with the exception of forests on slopes above residential areas that present active natural hazards. The latter type of forests were often put under a logging ban (*Bannwald* in German or *forêt mise à ban* in French), which means that the forest was and still can be classified as a reserved forest where felling is prohibited outright or selective thinning is only permitted under strict rules. In these forests, past management often consisted of 'doing nothing' (i.e. trees were rarely cut).

The main functions of forests recognised today include the production of timber and non-timber forest products, protection against natural hazards, recreation, nature conservation, watershed conservation, and sequestration of carbon dioxide (Buttoud 2000; Führer 2000; Price *et al.* 2000; UN-ECE/FAO 2000). The transition in forest management has occurred due to the increasing use of mountain areas and the diversification of Alpine economies, which have evolved from agricultural to tourism-based economies. As population densities and the economic value of the main alpine valleys have increased, the protection against natural hazards provided by forests has become more important (Schönenberger 2000). Forests traditionally designated as protection forests have now gained wider recognition due to their increasing importance as well as their direct economic and social benefits.

Protection forests are mainly designed to protect particular objects (Schönenberger 2000). This function implies that the forest directly protects people, buildings, and infrastructure against the impact of natural hazards such as snow avalanches and rockfall (Brang 2001). At the same time a forest provides a site-protection function, which is actually a prerequisite for the direct protective function. The site-protection function is important, as a forest stand needs to protect its site against processes such as excessive soil erosion. If the site-protection function is impaired, the forest site erodes, resulting in a loss of the forest ecosystem as a whole (Dorren *et al.* 2004a).

Unfortunately today's society has generally placed greater trust in technical protective works (e.g. engineered structures) than in protection forests. One of the reasons for this has been the lack of quantitative data on the efficacy of protection forests. Experience indicates that many of the protective works installed in the 1970s have had a shorter lifespan than originally planned. Replacement of these older structures has resulted in unforeseen expenditures. Secondly, a recent shift towards "ecological engineering" for natural hazard protection can be observed in the Alps. In addition, the knowledge and tools obtained from research during the last decade has enabled a quantitative assessment of how different mountain forests perform their protective function.

3 Good practices and mistakes in traditional protection forest management

An overview of former practices in European protection forests is provided by SUBOTSCH (1999), who compares the relevant forest laws and management strategies of Austria, France, Germany, Italy and Switzerland. The practices used in these countries to protect villages against rockfall are very similar, as they all more-or-less adopted a 'no intervention' policy in the past (18^{th} to mid 20^{th} century). In the surrounding or remaining forests, which mainly served for wood production, management was aimed at increasing the forest area and the standing volume (SCHÖNENBERGER 2000).

One traditional practice that was particularly useful was to allow inhabitants to carry out a basic geomorphological interpretation of the active natural hazards that posed potential direct threats. People working in the fields and forests were acutely aware of indicators of natural hazard indicators in the forests, such as the tracks or *couloirs* created by different types of mass movements (avalanche, rockfall, landslides and debris flows). By using these indicators and the experience of older generations, people could identify the types and locations of natural hazards. Evidence for this in the Alps is provided by the locations of village centres, which were generally located on the lower parts of alluvial fans from tributary valley systems, below a valley slope covered by a dense forest (Fig. 1). Such locations provided a number of advantages for villages:

- they had sufficient height above the main river to avoid flooding problems,
- they were far enough from the tributary torrential rivers to avoid damage by debris flows, and
- they were far enough from the bottom of the steep valley slopes to avoid rockfalls and avalanches that surpassed the forested zone.

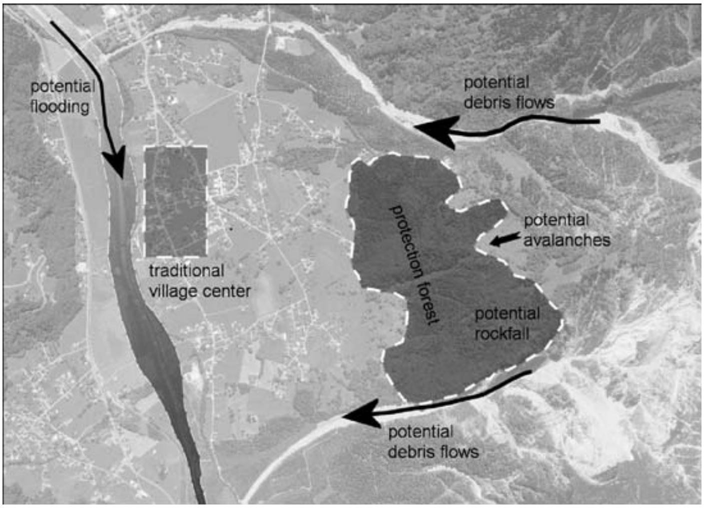

Fig. 1. Typical situation and location of a traditional village in the European Alps.

During the 19th century, mechanization was introduced and the demand for wood for industry and other uses increased. Many forests with no protective functions were cleared, leaving protection forests untouched. The only 'management' that took place in protection forests was the effect of natural disturbances (e.g. avalanches, wind throws, debris flows, and rockfalls). These processes caused the creation of couloirs and (selective) thinning. Despite these natural processes, many protection forest stands became very dense, leading to insufficient light for successful regeneration. In addition, clearcuts in the surrounding production forests, led to protection forests being used increasingly by ungulates for shelter. This, in combination with the suppression of predators by humans, led to high browsing pressures. As a consequence, regeneration was either insufficient or absent, leading to the development of even-aged, regular stands. Such stands cannot provide sufficient protection in the long term (AMMER 1996; MOTTA 1996, 2003; MOTTA and HAUDEMAND 2000). In addition, after the Second World War, the buffer zone between the traditional village centre and the foot of the forested valley slopes (Fig. 1) progressively disappeared due to housing pressures. Regional plans frequently ignored the existence of natural hazards and, as a consequence, the use of engineering works to protect villages has increased significantly since the 1970s. Protection forest restoration projects have also been initiated throughout the Alps. The 'no intervention' policy, combined with the inadequacies of recent regional planning, has created a number of problems and would be best avoided.

4 Technology for protection forest management

The forester, or any other practitioner, has to be able to quantify the state of the protective function of a forest stand for two reasons. Firstly, decisions have to be made as to which forests require silvicultural interventions to prevent an increase in the consequences of rockfall. Secondly, a quantification of the protective potential of a forest stand targets further, more detailed site investigations on the local rockfall hazard, as well as identifying future investments in rockfall-protection using combinations of civil engineering and forest management techniques. Before such an analysis can be undertaken, the location of protection forests in a management region and their current condition need to be understood. This information is required at the catchment scale, or at the scale of larger management areas (HAMILTON and BRUIJNZEEL 1997; ANDERSSON *et al.* 2000; HEROLD and ULMER 2001). Then, it is necessary to identify those forests with an impaired protective function. On the basis of these assessments, priorities for the restoration or maintenance of specific protection forest stands can be established (BERGER and RENAUD 1994; BERGER and LIEVOIS 1999). Some of the data can be collected from satellite images, orthophotos and laser scanning data. Additional stand details, such as tree diameter, species composition, structure, and stability, have to be generated through forest inventories, although a large amount of these data can be readily derived from laser scanning, albeit with less accuracy. The combination of forest inventory data and remotely sensed data in a Geographic Information System (GIS) provides a good database for forest management at both local and regional scales.

Computer simulation, spatial analysis, and GIS technology currently enable us to assess the effects of protection forests on natural hazards at the regional scale. DORREN and SEIJMONSBERGEN (2003) demonstrated how rockfall runout zones can be predicted at a regional scale, with and without taking into account the effect of protection forests. BERGER (1997) developed a method for assessing potential avalanche starting zones on forested and non-forested slopes. By combining the information on avalanche starting zones, active rockfall zones, a forest map, and a map with the elements at risk, a preliminary map with the locations of protection forests can be created, which will then require verification by local practitioners using orthophotos, terrain visits, and archives of historic events.

In addition to the above computer technologies, which have been adapted for regional scale analyses, technologies currently used for local scale analysis are able to account for the effects of protection forest stands and individual trees on natural hazards. Attempts have been made, for example, in snow avalanche simulation modelling (BARTELT and STÖCKLI 2001), in rockfall modelling (ZINGGELER *et al.* 1991; DORREN and SEIJMONSBERGEN 2003; DORREN *et al.* 2004b; STOFFEL *et al.* 2006) as well as in snow and wind damage studies (PELTOLA *et al.* 2000; GARDINER *et al.* 2000).

Dendrogeomorphology has been developed over the past 30 years (SHRODER 1980; STRUNK 1997). Information extracted from tree rings is being used to date, reconstruct, or map historic events. These techniques give insight into the interaction between trees and natural hazards, such as debris flows (e.g. SHRODER 1975; STRUNK 1989; WILKERSON and SCHMID 2003), rockfall (e.g STOFFEL *et al.* 2005) and avalanches (e.g. BUTLER and MALANSON 1985; SMITH *et al.* 1994).

Most forest and natural hazard studies require substantial amounts of data. Foresters need a small dataset formalized in a user-friendly tool if they are to evaluate the protective function of a forest stand rapidly and efficiently. The input data should be comprehensive and accurate, and should be easy to acquire in the field or using GIS, for example, at the scale of the slope or the forest stand. After acquiring the data, the forester needs guidelines to maintain or improve the protective function of the forest stand in question. Below, we provide examples of research and development activities in this area, and the tools that arose from them. The examples are related specifically to rockfall-protection forests.

4.1 Rockfall and forest research

The interaction between forests and falling rocks has been investigated in detail for the past 25 years (cf., COUVREUR 1982; JAHN 1988). GSTEIGER (1993) presented the concept of the "mean tree free distance" which he used to assess the protection against rockfall provided by a forest stand. This value refers to the average distance a rock travels between two tree contacts. It is assumed that forest stands whose mean tree free distance exceeds 40 meters cannot effectively slow down or stop falling rocks. Within such a distance, a rolling or bouncing rock on a 35 to 40° slope gains sufficient kinetic energy to break trees (DORREN *et al.* 2005). The protective capacity of the rockfall-protection forests is determined by the size of the falling rocks, the kinetic energy of the rocks, the stand density, and the mean tree diameter at breast height (DBH), and the tree species present. Small rocks have a lower tree contact probability than large rocks. The higher the stand density and the mean DBH, the higher the contact probability is. However, dense forest stands cannot be combined with large-diameter trees and high stability over the long-term. Juvenile forest phases generally show a high stand density with thin trees, whereas aging phases are mainly characterised by fewer and larger trees.

Several forest and rockfall experiments have been undertaken to obtain detailed information of the capacity of different trees to dissipate rockfall impact energy, to validate rockfall models, and to develop rockfall-protection forest management guidelines (e.g. COUVREUR 1982; JAHN 1988; CATTIAU *et al.* 1995; DOCHE 1997; BERGER *et al.* 2002; DORREN *et al.* 2005; STOKES *et al.* 2005). We carried out real-size rockfall experiments on forested and non-forested slopes, using high-speed digital cameras in the framework of the EU-project RockFor.

These experiments identified that mean slope gradient is the most important indicator for the possible movement of falling rocks. It is generally agreed that on slopes with a gradient greater than approximately 30° (60 %), rocks can start to roll (JOHN and SPANG 1979; JAHN 1988; GSTEIGER 1993; GERBER 1998). On shallower slopes, rolling rocks generally slow down and finally stop. Our experiments confirmed the results presented by GERBER (1998) that on slopes with a gradient of 35° (70 %) or more, rocks start to bounce. Other factors also affect a falling rock, such as its size and shape, the material covering the slope surface and the forest cover.

Our experiments clearly demonstrated that small trees are capable of stopping large rocks, given that a large portion of the kinetic energy has already been dissipated during preceding impacts. Analyses of rockfall impacts on silver fir (*Abies alba* Mill.) show that there is an exponential relationship between DBH and the maximal amount of energy that can be dissipated by a tree during a rockfall impact (DORREN and BERGER 2006). From our field observations and data analyses, we concluded that it is not only large trees that are required in a rockfall-protection forest; well-structured stands with a wide diameter distribution and a mosaic of different forest developmental phases provide the best protection. Furthermore, broadleaved trees appear to dissipate more energy during rock-tree contacts than coniferous trees. One of the better broadleaved trees regarding wound healing is the sycamore *(Acer pseudoplatanus)*. Although the wounds take longer to heal, European beech *(Fagus sylvatica)* can dissipate more rockfall impact energy, and their seedlings regenerate successfully in small openings due to their shade tolerance. Further details on the experiments and their results are described by DORREN *et al.* (2005).

4.2 A rockfall forest assessment tool

The free-of-charge and publicly accessible tool RockFor^{NET} (www.rockfor.net), developed by BERGER and DORREN (submitted), arose from our field experiments and modelling research. The model permits each user to calculate the probable residual rockfall hazard at the foot of a rockfall-protection forest. This is the percentage of rocks that pass through a forested slope and cannot be stopped in the forest stand or at the foot of the forested slope. RockFor^{NET} considers the existing forest as a spatially distributed rockfall net. It converts the existing forest structure into virtual rows of trees along the contour, with the distance between two trees in a row being equal to 90 % of the diameter of the dominant rock that falls at the site of interest. The distance between rows is 33 m. This distance has been derived from the mean tree free distance at our test site. To calculate this distance we adapted the basic concept presented by GSTEIGER (1993), in the sense that the total basal area is used as the most important parameter (DORREN *et al.* 2005). The results of our experiments demonstrated that the total basal area is an important indicator for the protective capacity of a forest stand. In addition, the basal area can be easily and quickly measured in the field using a relascope (BITTERLICH 1984).

In the model, all the trees in a row have a diameter equal to the mean DBH, which determines, in combination with the tree species, the efficacy of a tree in the energy dissipation during a rockfall impact. This follows the algorithms presented in DORREN and BERGER (2006). In order to calculate the probable rockfall hazard, RockFor^{NET} assesses how many rows are required with the mean DBH in order to protect the foot of the slope for 100 % of events, given:

- the slope length between the foot of the cliff and the foot of the forested slope,
- the height of the cliff,
- the length of the forested part of the slope,

– the rock density,
– the mean rock diameter, and
– the mean slope gradient.

These factors are required to calculate the energy to be dissipated by the forest stand. To do this, RockFor^{NET} uses the energy line angle, which is the angle of the straight line between the starting point and the maximum stopping point (HEIM 1932; TOPPE 1987; GERBER 1994). From the height difference between the energy line and the slope surface at the foot of the forested slope, the kinetic energy of the falling rock at the foot of the slope ($E_{k\text{-}foot}$) can be calculated. RockFor^{NET} assumes that the total amount of energy that has to be dissipated by the forest stand is 2.8 times the value of $E_{k\text{-}foot}$. BERGER and DORREN (submitted) found that the forest stand in which they carried out 102 real-size rockfall experiments dissipated on average 2.8 times as much as energy as the $E_{k\text{-}foot}$ calculated with the energy line. Finally, RockFor^{NET} compares the required number of trees with the existing number of trees in the stand and translates the difference between the two into a probable residual rockfall hazard (%).

The results of our experiments and of RockFor^{NET} have been formalised in silvicultural guidelines for mountain forests in France (ONF, in press) and in Switzerland (FREHNER *et al.* 2005). For the French guidelines, target values for rockfall-protection forest stands have been derived from Figure 2, which is produced by RockFor^{NET}.

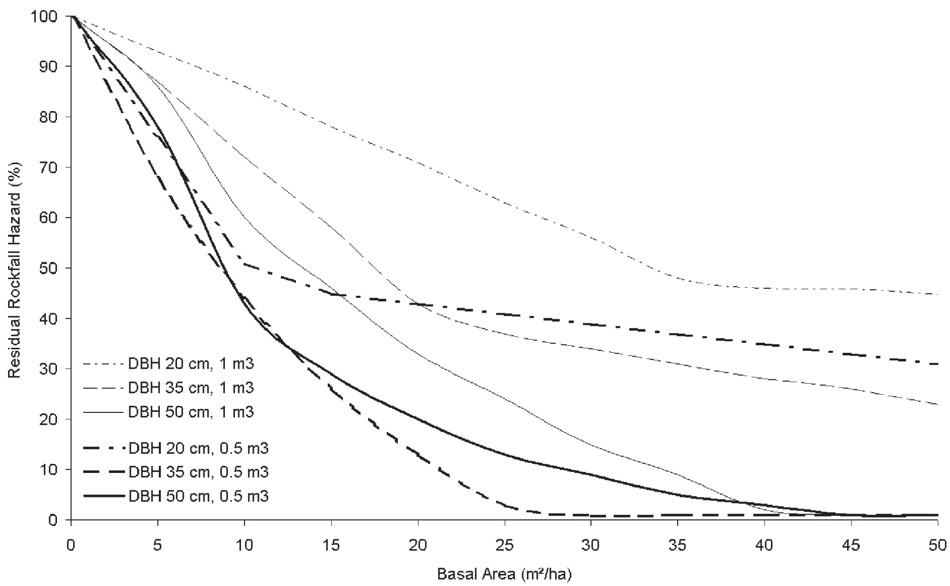

Fig. 2. Influence of the basal area of the forest stand on the residual rockfall hazard under a forested slope with a length of 500 m, a slope gradient of 38° and a rockfall source area with a of height of 10 m for different combinations of the mean tree diameter at breast height in the forest stand (DBH) and the volume of the falling rock.

5 Merging the best of two worlds: balancing tradition and technology

Taking into account the technological advances in protection forest research and management, as well as the good practices and mistakes made in the past, a useful merging of the technological and traditional world would be to take the experience of "landscape reading" (Fig. 3) and knowledge of natural hazard events of the past into account in the spatial planning and monitoring protection forests in order to assess whether there is a need for restoration or maintenance.

History has shown that doing nothing is not a sustainable practice. Forests can provide protection in the long-term only if a permanent tree cover is ensured by sufficient renewal (OTT 1978; ECKMÜLLNER 1988; KRÄUCHI *et al.* 2000; MOTTA and HAUDEMAND 2000; BRANG 2001; DORREN *et al.* 2004a). The remaining question is how much renewal would be sufficient (cf. WEHRLI *et al.* 2003) and how much removal can be accepted. Answers to these questions can be obtained by using models that simulate forest stand development to overcome the problem of the relatively slow response of forest ecosystems to 'close-to-nature' interventions. This type of intervention is currently used primarily in protection forests, which is also the result of the merging of tradition and research. Currently, these interventions are increasingly referred to as eco-engineering techniques. Examples include leaving trees diagonally on slopes in protection forests, building (temporal) protective structures, using locally felled trees and mixing silvicultural interventions with civil engineering for the time the forest needs to regenerate or restore.

Forest stand development simulation models can be used as a tool for assessing and predicting the level of protection provided by mountain forests in the future and for testing

Fig. 3. Snow avalanche track in the Montafon region (Austria), a good example of an indicator of a natural hazard (Photo L. Dorren).

silvicultural interventions (see LIU and ASHTON 1995; MLADENHOFF and BAKER 1999; PENG 2000, COURBAUD *et al.* 2001; JOHNSEN *et al.* 2001; WEHRLI 2005).

The technologies presented in this paper have been combined into a logical method for managing and sustaining protection forests (see flow diagram in Fig. 4). This method enables the identification of impaired protection forests in larger management areas and it allows for assessing where and which silvicultural interventions have to be carried out to safeguard protection against natural hazards, such as rockfall and snow avalanches. On the whole, such a method could contribute to an improvement in the management of mountain forests that protect against rockfall. This can be justified by two arguments. Firstly, the method results in better assignment of priorities for implementation of silvicultural measures at a regional scale. Secondly, silvicultural strategies within specific protection forests could be improved on the basis of the increased insight into the interaction between forest structure and rockfall as obtained by existing knowledge, local experience, and combined field and modelling studies.

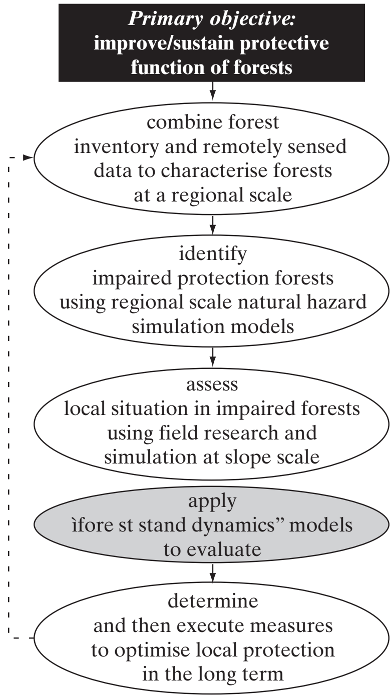

Fig. 4. Flow diagram showing how a combination of existing technologies could contribute to an improvement of the management of protection forests. The dotted arrow refers to monitoring, which focuses at a time step of five to ten years.

6 Conclusions

This paper reviews the current state-of-the-art of protection forest research and management in relation to rockfalls, focusing on traditional practices and present technologies. The traditional ‘do nothing’ approach is not an option for sustaining the protection provided by mountain forests. Management is needed – the question is how much.

A wide range of technologies are available to monitor, assess, simulate and assist in making decisions on specific silvicultural interventions and overall forest management. For this, the proposed general framework can assist in using the existing technologies.

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