

Management of protection forests in the European Alps: an overview

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Abstract

Protection forests are forests that have as their primary function the protection of people or assets against the impacts of natural hazards. The main 'product' of these forests are standing trees which act as obstacles to downslope mass movements such as rockfalls, snow avalanches, erosion, landslides, debris flows, and floods. The protective effect of these forests is ensured only if the silvicultural system used and any natural disturbances that occur leave a sufficient amount of forest cover. Management has therefore to take a very long-term perspective. This paper presents an overview of the occurrence and delimitation, ecology, stand structures and dynamics, and resistance and resilience of protection forests in the European Alps, and of suitable silvicultural systems. Guidelines for managing protection forests, which were developed collaboratively by Swiss forest managers and scientists, are described as an example of standardized decision-making in protection forests. Future research on protection forests should be directed towards synthesising existing knowledge in the natural sciences, engineering, and economics.

Keywords: protection forest, natural hazards, forest dynamics, forest management, stand structure, European Alps, decision-making

1 Introduction

This paper presents a short account of the ecology and management of forests that serve as protection against natural hazards. It is a revised and updated version of a book chapter on protection forests (BRANG *et al.* 2001). Consistent with our expertise, the focus is on natural hazards in mountain areas, primarily the European Alps.

Important terms used in this paper are defined in the annex. A protection (or protective) forest is a forest that has as its primary function the protection of people or assets against the impacts of natural hazards or adverse climate. Our definition implies the simultaneous presence of: i) a natural hazard or a potentially adverse climate that may cause damage, ii) people or assets that may be damaged, and iii) a forest that has the potential to prevent or mitigate this potential damage (SCHÖNENBERGER 1998). The term 'protection' designates the protection of people and infrastructure from natural hazards, and not of nature from human impact as in the term 'wilderness protection'. In this paper, we do not discuss the role of forests in protection from adverse climatic conditions (e.g. shelterbelts).

Protection forests may or may not be managed, and they may or may not fulfil other forest functions. In protection forests, however, the protective function is considered to be the dominant forest function.

1.1 How forests protect against natural hazards

The natural hazards that protection forests protect against include snow avalanches, rock-falls, shallow landslides, debris flows, surface erosion (caused by precipitation or by wind), and floods (also in flooded lowland areas, mangrove, and riparian forests). Most of these natural hazards are controlled by relief, and may therefore occur in combination.

From an ecological viewpoint, natural hazards are simply factors contributing to the natural disturbance regime. At any given site, the disturbances may occur at different frequencies and intensities. If disturbances occur frequently and with substantial impact, a forest is either unable to become established, or regularly destroyed in an early successional stage, and is therefore ineffective as a protection forest. This is the case with active snow avalanche tracks (JOHNSON 1987).

The protective ability of a protection forest is mainly provided by the presence of trees, which act as obstacles to mass movements. Tree stems halt falling stones (CATTIAU *et al.* 1995; DORREN *et al.* 2004; Fig. 1). Tree crowns prevent, by snow interception and by snow release, the build-up of a homogeneous snow layer that may glide as a compact blanket (IN DER GAND 1978). Tree roots reduce the hazard of shallow landslides (HAMILTON 1992; RICKLI *et al.* 2001). The permanent input of litter reduces surface erosion and increases the water-holding capacity of the soil through the build-up of an organic layer (cf. HAMILTON 1992). Tree roots can also increase the soil volume available for water storage, in particular on soils with moderate permeability (HEGG *et al.* 2005). Even dead trees lying on the ground may act as barriers to downslope mass transfers (MÖSSMER *et al.* 1994; FREY and THEE 2002; KUPFERSCHMID *et al.* 2003; SCHÖNENBERGER *et al.* 2005).

Forests can affect mass movements in the initiation, transport, and deposition zones. In the case of snow avalanches, shallow landslides, surface erosion, and floods, the main effect is



Fig. 1. A rock stopped by a tree (source Ernst Ott).

in the initiation zone: the forest prevents, or reduces, mass release. For other hazards, such as rockfall, release prevention is less important. For all hazards, forests may slow down, and eventually stop, mass movements in the transport and deposition zones. However, this effect is limited to small masses. Forests are usually unable to withstand large masses in motion, such as snow avalanches, boulders, and debris flows.

1.2 An important distinction: direct and indirect protection

Protection forests may be classified into forests offering direct and indirect protection. This classification is used, for example, in Italy and Switzerland. A given forest provides direct protection if the protective effect depends on the presence of the forest at a particular location. An example is a forest protecting a village against snow avalanches (Fig. 2). A forest with a direct protective function is usually restricted to a small area and protects a limited area below and close to the protection forest. Indirect protection depends only on the presence of a certain portion of forest at the landscape level, but not on its exact location. Examples include forests in catchments that have the potential to reduce soil erosion and peak flows (HAMILTON 1992). However, the old assumption that forests in the headwaters of a river mitigate or even prevent floods in remote lowland regions has been challenged (HAMILTON 1992; HEGG *et al.* 2005); in large catchments, several interacting factors seem to be at work.

The landscape or watershed level is important for the management of forests with an indirect protective function, but not for forests with a direct protective function. The latter are mainly managed at the stand level. Indirect protection is to some extent provided by any forest (e.g. forests generally act against soil erosion). Forests offering direct protection therefore always offer indirect protection, whereas the inverse is not true.

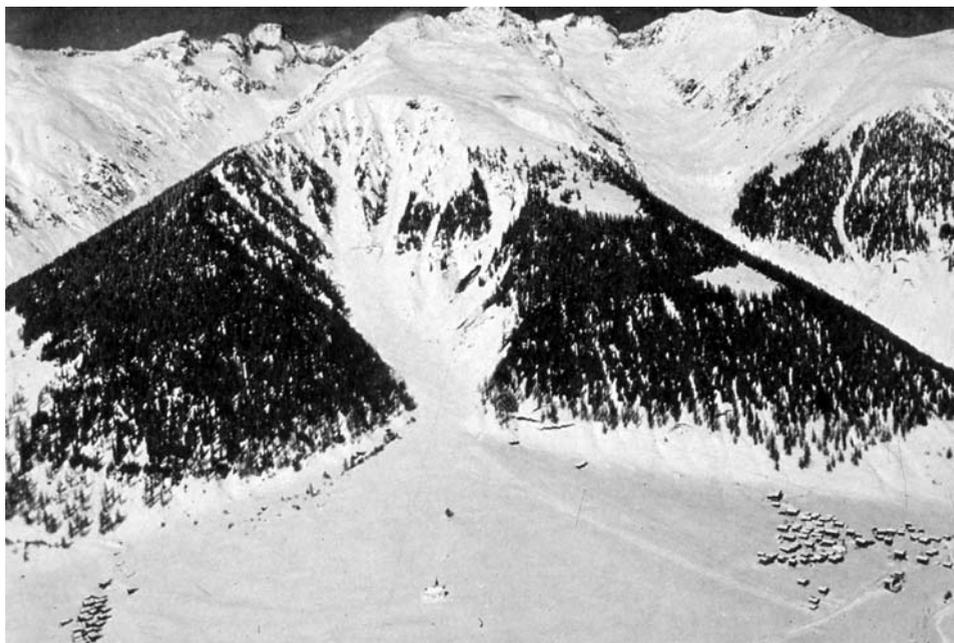


Fig. 2. Protection forests above Ritzingen and Gluringen, Wallis, Switzerland.

1.3 Limits of forest influence: if a forest alone is insufficient

The effectiveness and reliability of the protection provided by a forest depends on the natural hazards involved, the frequency and the intensity of damaging events, and the condition of the protection forest. In many cases, protection forests effectively protect against natural hazards. Sometimes, however, the residual risks are high, e.g. if the damage potential is very high, or if a forested slope is too short to stop rocks falling from a cliff. Such situations occur often above settlements or major roads. The hazards may also develop temporarily after a disturbance, until a new tree generation re-establishes the protective effect.

Solutions for such cases are artificial defence constructions (avalanche barriers, rockfall nets, terraces, poles and tripods driven into the ground as shown in Fig. 3, and dams). Even in these cases, however, the additional effect of the forest may be important. It is also possible to limit potential damage by moving the elements at risk (e.g. building a road on the other side of a valley, or land use planning).



Fig. 3. Wooden tripods which prevent snow gliding and enable planted trees to pass the threatened juvenile phase. Vaujany, Savoie, France.

2 Occurrence and delimitation of protection forests

As many types of natural hazards are gravity-driven, and therefore restricted to a minimum slope angle in suitable terrain, protection forests are prominent on steep slopes in mountain regions. In mountain protection forests in the temperate zone, the prevalent natural hazards are snow avalanches, torrents, and rockfall, whereas in the protection forests of the subtropics and tropics, soil erosion and landslides, both caused primarily by high precipitation events, are more prominent. However, protection forests occur also in valley bottoms or on fans where they may protect against floods or surface erosion.

In the Swiss National Forest Inventory, evidence of erosion was recorded on 16 % of the plots in mountain regions, evidence of moving snow was found on 37 %, and evidence of rockfall on 31 % (EAFV and BFL 1988 p. 85). In publicly-owned French mountain forests, the dominant natural hazards were torrent erosion (65 % of the area), snow avalanches (14 %), rockfall (10.5 %), and landslides (10.5 %) (SONNIER 1991). In the Bavarian Alps of south-eastern Germany, 63 % of the forests are estimated to provide protection against soil

erosion and debris flows, 42 % against avalanches, and 64 % against floods (PLOCHMANN 1985). Despite obvious differences in methodology, these figures clearly reveal the importance of forests in reducing natural hazards in mountain regions.

However, the absence of a common methodology in assessing protection forests clearly points to the difficulties in definition and delimitation of protection forests. Such delimitation is important because the management of protection forests is in general more restrictive than in other forests. The difficulties in delimiting protection forests are: i) insufficient understanding of mass movement processes (e.g. in runout zones), ii) different assumptions about return intervals of natural hazards, depending on the level of safety under consideration, iii) a disinterest in small-scale mosaics with different forest functions (because it hinders efficient management), and iv) a trend to generous interpretation of delimitation rules if subsidies for protection forest management are available.

Even in a small country such as Switzerland, where special management approaches for protection forests have been in use for more than 30 years, there is no common and consistent delimitation of protection forests. Such a delimitation effort has only recently been started (project SilvaProtect-CH, <http://www.bafu.ch>, accessed 10 February 2006).

For mapping protection forests, technologies such as digital terrain models, hazard simulation models, and remote sensing, including LIDAR, are increasingly used (DORREN *et al.* 2004). This enables a more objective assessment and delimitation of protection forests, although careful ground-truthing is still required.

3 Stand dynamics, stand structures, resistance and resilience in protection forests in the Alps

Managing protection forests means influencing forest dynamics, and understanding these dynamics is therefore a prerequisite for effective management. In this section, we focus first on natural disturbance regimes in protection forests in the Alps, and on the impact of disturbances on the protective effect. Next, we examine the resistance of stands against disturbances and their resilience (more specifically, the speed of recovery) after disturbance. Finally, we explore which stand structures are desirable.

3.1 Why small-scale disturbances prevail in protection forests in the Alps

In protection forests in the Alps, both large- and small-scale disturbance regimes are present, but the latter prevail (ZUKRIGL 1991), with single disturbance events affecting areas that are usually smaller than 0.1 ha. This is especially true in the montane belt (mixed *Fagus sylvatica* *Abies alba* *Picea abies* forests; ZUKRIGL 1991) and under cool and wet site conditions (e.g. in many subalpine forests close to the treeline). The small-scale disturbance regime leads to the continuous dominance of shade-tolerant species.

Large-scale disturbances are uncommon in the European Alps for several reasons. Firstly, the propagation of disturbances is often limited because large contiguous forest areas are rare. Forests occur in patches due to avalanche tracks, the upper treeline, and agricultural land. Secondly, the terrain is often very rugged, resulting in small-scale variability in site conditions and, consequently, in tree species composition and seral stages. This hinders widespread disturbances from forest fires, storms, and bark beetles. Thirdly, high summer precipitation, low intensity of thunderstorms, and low fuel loads resulting from past intensive forest use, mean that large-scale fires are rare events in the Alps. This situation is completely different to that found in many North American mountain forests where vast continuous

forest areas, high fuel loads, summer drought and intense thunderstorms result in frequent large-scale fires (KIMMINS 1997, p. 296).

Nevertheless, the large-scale disturbances that do occur in mountain forests in the European Alps are particularly relevant because of the impact on the protective effect of the forests. They are mainly caused by storms, snow load, bark beetles, and fire. Fire is important in *Pinus sylvestris* forests in the continental climate of the inner Alps, where summer drought periodically leads to high fire hazard (WOHLGEMUTH *et al.* 2005). Fire also periodically disturbs various forest ecosystems in the Southern Alps, as a consequence of winter and early spring droughts. The forest ecosystems in the Alps that are susceptible to large-scale disturbances other than fire are mostly forests with a single-species tree layer of *Picea abies* (in the montane and subalpine belts). Pure *Picea abies* stands tend, with the exception of extreme site conditions in the subalpine belt, to form relatively dense homogeneous stands, with high intraspecific competition, short crowns and similar tree age and height (KORPEL' 1995). This natural tendency has often been reinforced by large-scale clear-cutting and by afforestation.

3.2 Impact of disturbances on the protective effect

The impact of disturbances on the protective effect of a mountain forest varies considerably. While fires have the potential to impair the protective effect in large contiguous areas, snow load usually leaves many surviving trees that partly maintain the protective effect. The impact of storms on the protective effect is highly variable. Some storms have only a thinning effect, others destroy entire stands. During the first decades after a storm, uncleared windthrow areas may provide even higher protection than the former forest (e.g. against rockfall). Leaving windthrow strongly affects the protective effect due to the presence of many obstacles to downslope mass movements (SCHÖNENBERGER *et al.* 2005). However, the protective effect of the remaining downed timber and of root-plates declines with time (FREY and THEE 2002). Bark beetles often kill any remaining trees after disturbance caused by a storm or snow load, particularly the beetle *Ips typographus* in *Picea abies* forests (HEURICH 2001).

3.3 Characteristics favouring and impeding resistance of the tree layer to disturbance

A stand with a direct protective function should be permanently effective. This is only the case if a tree layer is permanently in place. Several ecological characteristics of subalpine and montane forests favour the permanence of the tree layer, while others counteract it. In general, smaller trees are more resistant to disturbance agents such as storms and snow load than tall ones, and broad-leaved trees are more resistant than conifers (KÖNIG 1995, MAYER *et al.* 2005). In contrast, the question of increased resistance through preventive cutting is controversial. While scientific evidence for higher resistance of heterogeneous stands is weak (MASON 2002, but see DVORÁK *et al.* 2001), and the effects found in large-scale studies are small (BRANG *et al.* 2004), forest managers often claim such relationships, arguing that there is less sunscald and consequential disturbance in heterogeneous stands. Whatever, it is more effective to influence the resistance of a forest while it is still young rather than later.

In subalpine forests, the resistance of the coniferous tree layer to disturbance agents such as storms and snow load is enhanced by a low coefficient of slenderness of the stems (ROTTMANN 1985; STROBEL 1997), a low centre of gravity of the trees (STROBEL 1997), and a clumped stand structure (Fig. 4), which is caused by high microsite variability and favoured

by steep environmental gradients within gaps. Stands with a clustered structure contain long internal edges that often act as breaks to natural disturbances, preventing a ‘domino’ effect where each fallen tree triggers the fall of adjacent trees (SCHÖNENBERGER 2001). However, the high resistance of clustered stand structures is only intuitively understood (see MĚLNSEK 1975), whereas the low resistance to disturbance of homogeneous stand structures, with slender stems, short crowns with high centres of gravity, and no internal edges is obvious and has been repeatedly demonstrated (CERNY 1980; PETTY and WORRELL 1981; SAVILL 1983; ROTTMANN 1985; SLODICÁK 1995). These stand characteristics can be influenced by thinning in young stands.

Homogeneous stand structures are common in forest ecosystems with low microsite variability, large-scale disturbance regimes, and only one canopy tree species. With increasing altitude, homogeneous stand structures become increasingly rare in natural forest ecosystems, and heterogeneous stands dominate. Homogeneous stand structures are often a consequence of clear-cutting with subsequent natural or artificial regeneration, or of homogeneous afforestations that were subsequently left untended – a common situation in the Alps (SCHÖNENBERGER 2001).

3.4 Factors favouring and impeding recovery from disturbance

The disturbance regime of a forest ecosystem always includes disturbances of a magnitude that break the resistance of individual to many trees, by uprooting, breaking, or killing them as standing trees. This frees resources (e.g. growing space, light, water, and nutrients), and initiates a recovery process. Silvicultural interventions are often intended to have the same effect. In subalpine forests, the infrequent years with seed production (MENCUCCINI *et al.* 1995), the sparse or missing seedling bank, and the slow tree growth result in a recovery of the tree layer after major disturbances that usually takes several decades (SCHÖNENBERGER



Fig. 4. Open stand structure of a subalpine *Picea abies* forest (source: Ernst Ott).

2002). The recovery depends in many environments on nurse logs favourable to coniferous regeneration (HARMON *et al.* 1986). The sparse occurrence of nurse logs (Fig. 5) in most managed forests (BRETZ GUBY and DOBBERTIN 1996) is therefore a serious impediment to natural seedling establishment (BRANG 1996). The long crowns of canopy trees occurring in clusters often locally suppress vegetation development, so that, after removal of a tree cluster by a disturbance, there is an opportunity for seedling establishment (SCHÖNENBERGER 2001). Such microsites, however, are only suitable for regeneration for a limited time as not only tree seedlings, but also other vegetation compete for the available resources. A dense cover of mosses, herbs, grasses, and shrubs often completely prevents tree seedling establishment (IMBECK and OTT 1987; COATES *et al.* 1991; BRANG 1996). Seedling establishment may also be impaired by pathogenic fungi (e.g. *Herpotrichia*, *Gremmeniella*) and snow gliding (SCHÖNENBERGER *et al.* 1990). Browsing ungulates are another impediment to tree seedling establishment. Browsing often reduces height growth (PUTNAM 1996), prolonging the phase of high susceptibility of seedlings to further damage by factors such as pathogenic fungi and snow press. Heavy browsing may change the species composition or even completely prevent tree seedling establishment (GILL 1992; AMMER 1996; PUTNAM 1996).

The frequency and intensity of some disturbances (e.g. snow load, wind) usually increase from montane to subalpine forests, but this may be balanced by the increasing resistance (for definition see annex) of the trees. Hence, there is no general relationship between persistence of the tree layer and altitude. Recovery times, however, become longer with increasing altitude, as the harsh climate in subalpine forests results in slow growth of tree seedlings (SCHÖNENBERGER *et al.* 1995). Coniferous seedlings which are suppressed by canopy trees often exhibit annual height growth rates lower than 1 cm (METTIN 1977; KOPPENAAL *et al.* 1995). In subalpine *Picea abies* forests, it may therefore take 30 to 50 years until a seedling has outgrown the average snowpack depth of 1 to 2 m (BRANG and DUC 2002). In montane forests, even heavily suppressed *Picea abies* seedlings usually grow considerably faster, with annual height growth rates of 3 to 4 cm (SCHÜTZ 1969; MOSANDL and EL KATEB 1988), similar to height growth rates in *Tsuga mertensiana* and *Abies* sp. in south-central Oregon, United States (SEIDEL 1985).

3.5 How should a protection forest be structured?

There is no general rule as to how a protection stand should be structured because this depends on the specific natural hazards that are present. In a static view, a protection forest should provide as many obstacles to the downslope movement of material as possible. The



Fig. 5. Naturally established seedlings on a nurse log in a subalpine *Abies lasiocarpa* *Picea engelmannii* forest in British Columbia, Canada.

forest should therefore ideally consist of as many trees as possible of the minimum effective tree size for the hazard in question. This means the highest possible stand density for the effective tree size. However, there are biological limits to high stand density since competition will either reduce the number of trees (mortality), or hinder trees from growing to large size. Moreover, there may be no change in protective effect with a change of tree size; more but smaller trees may be similar in protective effect to fewer larger ones. In forests protecting against small rocks, for instance, the protective effect of many small trees may even be greater than the effect of a few large trees. In addition, high stand density often involves reduced resistance of trees to disturbances (KORPEL' 1995): Natural disturbances such as storm events reduce the proportion of forest with high density, and create stands with smaller protective effect (e.g. young growth stages). Anthropogenic disturbances, such as silvicultural operations, have a similar effect. Stand renewal is therefore often the weak link in the chain of forest dynamics. So, a general target stand structure could be to have as many trees as biologically possible in the long-term, without impairing individual tree resistance to disturbance and forest renewal.

The natural hazards at a given site determine the minimum requirements for stand structures to ensure permanent protection (SAKALS *et al.* this issue). If rockfall is prevalent, dense stands, with small inter-tree distances (gaps) parallel to the slope, are most effective (OMURA and MARUMO 1988; ZINGGELER *et al.* 1991; GSTEIGER 1993; CATTIAU *et al.* 1995; DORREN *et al.* 2004). If snow avalanches prevail, gap size requirements are similar (Table 1), but stand density is less important, and coniferous trees are more effective than deciduous trees in preventing avalanche release in the forest (SCHNEEBELI and MEYER-GRASS 1993). Based on the available knowledge, minimum requirements regarding stand structures can be defined – an approach taken in Switzerland (FREHNER *et al.* 2005; see Chapter 5 of this paper). Such requirements should include a margin of safety because disturbances can easily impair effective protection.

A special case relates to dead trees. It is increasingly recognised that the stems, root-plates, and stumps of dead trees may have similar protective effects to living trees. Results obtained from unharvested Swiss windthrow sites and snag stands monitored for ten years demonstrate that this material has had a very high protective effect (FREY and THEE 2002; KUPFERSCHMID *et al.* 2003; SCHÖNENBERGER *et al.* 2005). However, ten years after the disturbance, this effect is clearly decreasing due to decay. No long-term data are available to estimate how quickly this decay will proceed, and under which conditions forest renewal will be able to replace the decreasing protective effect of the wood. Currently, research suggests that the time span for effective protection provided by downed woody debris timber is approximately 30 years (FREY and THEE 2002; KUPFERSCHMID *et al.* 2003).

Table 1. Threshold values for gap length and canopy cover to avoid snow avalanche release in subalpine and upper montane coniferous forests in the Alps (FREHNER *et al.* 2005, annex 1, p. 3)

^a If critical values for gap length are exceeded, the gap width should be smaller than 5 m

^b In evergreen coniferous forests, avalanches are not expected to release if the slope is less than 35°. In larch forests, however, which often have ground vegetation consisting of grass and thus smaller surface roughness, avalanches may release on slopes as low as 30°.

Characteristic	critical value
Gap length parallel to the slope ^a (edge defined by crown projection)	<60 m if slope $\geq 30^\circ$ ^b
	<50 m if slope $\geq 35^\circ$
	<40 m if slope $\geq 40^\circ$
	<30 m if slope $\geq 45^\circ$
Canopy cover	>50 % cover

4 Silvicultural systems for protection forests

4.1 Suitability of silvicultural systems

Managing forests for their protective effect is clearly different to managing for timber production since the 'product' of a protection forest is not bound to what is removed but to what is left in the forest. In many cases, conventional clearcutting or seed-tree cutting, which leave no or only few trees standing after a harvesting operation, are unsuitable for protection forests since they impair the protective effect (SCHÖNENBERGER and BRANG 2004). Silvicultural systems that leave more trees on-site and ensure renewal of forest cover, such as shelterwood, border-cutting, selection, or coppice systems, are more suitable. The management restrictions are clearly more important for direct protection than for indirect protection. For direct protection, the best compromise between protective requirements and the long-term protective capacity of a forest is a natural or anthropogenic small-scale disturbance regime that creates a mosaic of developmental phases (CHAUVIN *et al.* 1994; OTT *et al.* 1997). This will result in a small-scale patchwork of trees of all ages and sizes, with only small patches where no trees act as obstacles against mass movements (SCHÖNENBERGER 2001; Fig. 4). An alternative to such mountain selection forests are coppice forests with a high stem density, which are effective in halting falling rocks in run-out zones (GSTEIGER 1993).

On steep slopes, management is not only restricted by protective requirements, but also by the feasibility and costs of timber harvesting. If the forest owners cannot profit from a harvesting operation, or if they cannot afford to pay the extra costs, only a few solutions remain: i) stop harvesting trees, ii) harvest more trees per unit area to reduce unit harvesting costs, or iii) seek funding to cover the additional expenses.

4.2 Leaving protection forests unmanaged: a good solution?

In recent decades, leaving formerly managed protection forests unmanaged has become a reality in large areas because timber harvesting is often too costly on steep slopes. In protection forests, a no-intervention strategy has several advantages, but also has risks. The advantages are: i) there are no management costs, ii) risks for forest workers involved with steep slope harvesting are avoided, as are risks for the objects being protected (e.g. release of stones), iii) the protective effect usually increases, at least temporarily until disturbances occur, and iv) rare species dependent on old-growth forest characteristics may regain habitat. However, there are also risks involved with an unmanaged protection forest: i) the resistance of the stands against disturbances is likely to diminish (in particular if these stands reach high stand density as described in 3.5; KORPEL' 1995), ii) leaving disturbed forest areas, such as windthrow areas, uncleared may trigger bark beetle outbreaks (WERMELINGER 2004) or promote forest fires, and iii) disturbed and uncleared areas provide insufficient protection in the mid-term if the timber decays rapidly and regeneration grows slowly (SCHÖNENBERGER *et al.* 2005). As silvicultural interventions are often effective in promoting the establishment of advanced regeneration, recovery after disturbance is usually faster in forests that have received selective cutting (BRANG 2001).

In Switzerland, leaving protection forests unmanaged has gained qualified acceptance among forest managers over the last ten years. Given the unknowns involved with this management option, it is not accepted in situations where the damage potential is high – forests protecting houses or major roads. However, the uncertainty is increasingly accepted if the damage potential is small. The Swiss guidelines for managing protection forests

(FREHNER *et al.* 2005, see Chapter 5) even prescribe that an operation that is not clearly cost-effective should not be undertaken. Cost-effectiveness implies that the benefits expected are high and reasonably certain in relation to the costs (which are easier to estimate and therefore quite certain).

4.3 How natural should the structure of a protection forest be?

Natural disturbance regimes may not produce the patchwork described as the ideal for a protection forest (see 3.5), creating forests with insufficient protection. An example is a montane *Picea abies* forest affected by a windstorm. Natural disturbances may have even more devastating effects in forests with a long history of heavy anthropogenic impact than in forests subject to natural disturbance regimes alone. The anthropogenic impact may have moved stand conditions far away from the natural range of variability (e.g. by forming large stands with homogeneous structure) (OTT *et al.* 1997). This situation is common in the European Alps. Lack of management intervention, and relying on natural disturbances is often a risky management strategy in such cases.

However, the long-term goal of a close affinity to naturalness is still justifiable for three reasons. First, deviations from natural forest dynamics have often impaired effective protection over the long-term, particularly in the subalpine belt. Second, ecosystem processes knowledge is currently too limited to enable the ‘design’, creation, and maintenance of protective forest ecosystems, although it may be possible to design protective tree stands for limited time periods. Third, management experience indicates that a close affinity to ‘naturalness’ is often cost-effective in the long-term. It is therefore advisable to rely on natural ecosystem dynamics that have resulted in a permanent and effective forest cover over centuries and millennia.

In addition, modifications of the stand structures are not simply feasible in the short term – current stands determine possible pathways of management (OTT *et al.* 1997). It may take many decades or even centuries of silvicultural interventions to reach optimum stand structures for continuous protection.

5 Managing protection forests: an exemplary approach

How should protection forests be managed to ensure their long-term effectiveness? How can stand structures with sufficient protective effect be achieved and continuously maintained? In the European Alps, similar questions have been explored for many decades, and practical, though preliminary, solutions are now available. Several procedures have been developed to assist decision-making for protection forests (CHAUVIN *et al.* 1994; RENAUD *et al.* 1994; WASSER and FREHNER 1996; FREHNER *et al.* 2005; ANGST in press).

This section presents a description of a procedure that was developed and is now being implemented in Switzerland (FREHNER *et al.* 2005). Guidelines derived from this model are anticipated to appear soon in several Alpine countries. The procedure will be updated as knowledge of protection forests increases. A major feature of the procedure is standardized decision-making, based on the best available information. It was developed collaboratively by forest managers and scientists.

5.1 Principles

Seven guiding principles help to ensure the cost-effective management of protection forests. First, any intervention must maintain a sufficient protective effect. Second, such interventions must be carried out at the right place – where they are likely to have a positive effect. Third, they must be carried out at the right time – when the relation between their effect and their cost is as high as possible. Fourth, such interventions should be in accordance with natural forest dynamics and tailored to site conditions, ensuring efficient use of natural processes. Fifth, there should be a standardized, transparent decision-making process that enables silvicultural assessments. Sixth, such interventions should be effective – have a high probability of success. Seventh, their benefits should clearly exceed the costs.

5.2 Target profiles

The general approach is based on a comparison between the current condition of a given stand and a target condition. The target condition, which is a description of stand structural characteristics, is specific for both a natural hazard and site conditions, and is formalized in ‘target profiles’. The natural hazard target profile describes how a forest should be structured to prevent a natural hazard from causing damage. Standards with regard to stem number, gap size, and forest cover vary with the natural hazard, and are explicit in the profile. Conversely, the site condition target profile describes how a forest should be structured to ensure effective protection in the long term (i.e. to be resistant to disturbance and resilient after it). These site-related profiles propose standards with regard to species mixture, horizontal and vertical stand structure, and regeneration.

For both hazard- and site-related target profiles, there are two sub-profiles, one describing an ‘ideal’ forest condition and one describing a ‘minimum’ condition. The ‘ideal’ profile describes the long-term silvicultural objective, and the ‘minimum’ profile serves as the lower threshold for carrying out silvicultural interventions.

There are four different hazard-specific target profiles: i) snow avalanches, ii) landslides, erosion, and debris flow, iii) rockfall, and iv) torrents and floods. These hazard-specific target profiles are further specified, where appropriate, for release, transport, and run-out areas. As a result, there are 121 site-specific target profiles.

Both the minimum hazard-related target profile and the minimum site-related target profile need to be met to ensure effective protection. An example of a hazard-related target profile is presented in Table 2, and an example of a site-related target profile is presented in Table 3.

Table 2. Example target profile for natural hazards: Forest on slopes with rockfall (FREHNER *et al.* 2005, Annex 1, p. 14).

^a The target diameter has to be chosen so that the required stem density with stems of the effective minimum diameter can be permanently maintained.

^b Gap: opening from crown edge to crown edge in pole and old timber stands.

Zone	Potential contribution of forest	Minimum standard	Ideal standard
Release zone	Medium	'Backbone' trees No unstable heavy trees	
Transit zone	High Rocks up to 0.05 m ³ (diameter about 40 cm)	Horizontal structure ≥ 400 trees/ha with DBH >12 cm	Horizontal structure ≥ 600 trees/ha with DBH >12 cm
		potentially also coppice	
		Vertical structure Target diameter ^a appropriate	
	Rocks 0.05 to 0.20 m ³ (diameter about 40 to 60 cm)	Horizontal structure ≥ 300 trees/ha with DBH >24 cm	Horizontal structure ≥400 trees/ha with DBH >24 cm
		Vertical structure Target diameter ^a appropriate	
	Rocks 0.20 to 5.00 m ³ (diameter about 60 to 180 cm)	Horizontal structure ≥150 trees/ha with DBH >36 cm	Horizontal structure ≥200 trees/ha with DBH >36 cm
Additionally for all rock sizes	Horizontal structure If gaps ^b exist in slope direction: stem distance <20 m Lying logs and high stumps as complement to standing trees, if no risk of fall		
	Stand meets criteria of minimum site-specific standard	Stand meets criteria of ideal site-specific standard	
Runout and deposition zones	High The effective minimum diameter of trees is considerably smaller than in the transit zone, and lying logs are always effective	Horizontal structure ≥400 trees/ha with DBH >12 cm	Horizontal structure ≥600 trees/ha with DBH >12 cm
		Horizontal structure If gaps ^b exist in slope direction: stem distance <20 m, potentially also coppice	
		Vertical structure Target diameter ^a appropriate Lying logs and high stumps as complement to standing trees	
		Stand meets criteria of minimum site-specific standard	Stand meets criteria of ideal site-specific standard

Table 3. Target profile for specific site conditions: example of the site associations *Adenostylo-Piceetum typicum* and *Adenostylo-Piceetum athyrietosum distentifolii*¹ (FREHNER *et al.* 2005, Appendix 2B, p. 35).

¹ Number and nomenclature of site associations according to ELLENBERG and KLÖTZLI (1972)

Characteristics of a stand or of individual trees	Minimum standard	Ideal standard
Mixture		
Type and degree	<i>Picea abies</i> 70–100 % <i>Sorbus aucuparia</i> , <i>Alnus viridis</i> Seed trees, up to 30 %	<i>Picea abies</i> 90–95 % <i>Sorbus aucuparia</i> , <i>Alnus viridis</i> 10 %
Structure		
DBH distribution	Sufficient density of trees with development potential, in at least 2 different DBH classes per ha Clusters, possibly individual trees	Sufficient density of trees with development potential, in at least 3 different DBH classes per ha Clusters, possibly individual trees Canopy cover loose to open
Horizontal structure		
'Backbone' trees		
Crowns	Crown length at least 2/3	Crowns reaching the ground
Verticality/anchoring	Mostly vertical trees with good anchoring, only isolated strongly leaning trees	Vertical trees with good anchoring, no strongly leaning trees
Regeneration		
Seedbed	Rotten wood present every 10 m (100 spots/ha)	Rotten wood present every 8 m (150 spots/ha)
Seedlings (10 cm to 40 cm height)	<i>Picea abies</i> and <i>Sorbus aucuparia</i> present on at least 1/3 of microsites favourable for seedlings	<i>Picea abies</i> and <i>Sorbus aucuparia</i> present on at least 1/2 of microsites favourable for seedlings
Saplings (up to the thicket stage, 40 cm height to 12 cm DBH)	At least 70 sapling groups (saplings) per ha (on average one group every 12 m) Mixture meets target values	At least 100 sapling groups (saplings) per ha (on average one group every 10 m) Mixture meets target values

5.3 The decision-making process

Decisions are made at catchment and stand levels. First, a catchment or landscape is subdivided into areas with the same combined hazard- and site-specific profiles, termed target types. To determine the most appropriate profiles, information on natural hazards and a site map are required.

Stands that are similar with respect to their current stand structure and target profile are then grouped into treatment types. Decisions are made, and the assessments done, on one indicator plot of about 1 ha size that is selected to be representative for the treatment type in question. The current state of the forest on the indicator plot and its predicted state in 10 and 50 years are compared to the target profile, using a checklist (Table 4) with the indicators shown in Table 3. If the forest condition expected in 50 years does not meet the target profile, and if there are effective and justifiable operations to influence forest development positively, action should be taken.

The cost of an intervention is an important issue because cable or helicopter logging is often the only option available for timber harvest. Revenue generated through interventions may therefore not cover the costs. In some cases no intervention is the most appropriate

solution: 'The wisdom of a forester does not become evident in what he does, but in what he leaves' (ZELLER 1982). The slow development of many mountain forests requires a patient approach to management. If we utilize natural processes to achieve desired changes in stand composition and structure, and this should be our general approach, the changes may take several decades (WEHRLI *et al.* this issue). Any action should be taken at the time when it has the highest effect. This may not be now, but only in ten, thirty, or fifty years, although interventions in young stands are often very effective and can be done at low cost.

5.4 Silvicultural toolbox

Stem extraction (timber harvest) is often the most effective intervention to direct a stand toward target stand conditions, particularly because it changes the stand structure. Often, it is also justifiable because revenues cover the costs. However, the removal of trees often temporarily reduces the resistance of a stand to storms and snow load, leading to damage of the tree layer (OTT *et al.* 1997). Such destabilisation can be mitigated or prevented if the dominant trees with a relatively low coefficient of slenderness are left on site, and if any existing tree clusters are either entirely left or removed (OTT *et al.* 1997).

Stem extraction is not the only option that should be considered. Other options may be cheaper and more effective. Alternative interventions include felling without extraction, creation of microsites favourable for natural seedling establishment such as mounds (BASSMANN 1989) and mineral soil (PRÉVOST 1992), sowing, planting, vegetation control, game control, tending of young stands (SCHÖNENBERGER *et al.* 1990), and the artificial creation of clusters (SCHÖNENBERGER 2001).

5.5 Assessment

The standardised decision-making procedure is important for monitoring the success of management actions, which in turn helps to improve management through adaptive management (WALTERS 1986). Assessment in protection forests encompasses four steps. The first, an assessment of the interventions checks whether they were carried out professionally and at the right place. The second, an analysis of the effectiveness checks whether the interventions had the expected effect on forest development. These two steps take place in the forest that is being managed, in particular on the indicator plots, and should be properly documented. Documentation includes information on the decision-making process, the interventions carried out, and the outcomes. The indicator plots need to be carefully described and permanently marked. Proper documentation is important for assessing the effectiveness of interventions because short-term success may become long-term failure. Monitoring should therefore be conducted over decades. This is due to the role of infrequent, extreme climatic and biotic events in forest dynamics. Homogeneous afforestations that initially establish successfully, but later become unstable, are a good example.

The last two assessment steps consider a larger scale. The third, a regional assessment enables an overview of the protective effectiveness of the forests, and fourth, the target analysis checks whether the profiles used for decision-making need revision due to new knowledge.

In addition to these assessment activities, it is also possible to design interventions as simple controlled experiments. However, any treatments in forests with a direct protective function must maintain effective protection. To test a wide range of experimental treatments, forests with only an indirect protective function are more appropriate (BACHOFEN and ZINGG 2001).

Table 4. Example of a completed checklist to determine the need of action in a protection forest.

Municipality: Amden		Locality: Stienwald	Indicator plot no. 5	Decision-making table		Author: N.N.
1. Site type(s)		25C				
2. Natural hazard and effectiveness		rockfall transition zone, rock size up to 50 cm, high protective potential of forest				
3. Condition, trend analysis and interventions		Present condition	Present condition, trend in 10 & in 50 years	Effective interventions	6. Intermediate target To be checked in 10 years (in year 2012)	
Stand and single tree characteristics (including natural hazards)		Minimum standard (including natural hazards)				
• Species mixture (type and degree)	lime, maple, ash, oak, other broad-leaved trees 50-100%, conifers 0-10%	lime, maple, ash, larch, spruce, hazel, other broad leaved trees 60%, spruce 15%, larch 25%			lime, maple, ash, larch, spruce; broad leaved trees 75%, spruce 10%, larch 15%, hazel	
• Vertical structure (diameter distribution)	enough viable trees in two DBH classes on each ha, only few trees >50 cm	DBH classes 20-40 cm well represented 45 conifers/ha >52 cm 9 broad-leaves/ha >52 cm			DBH classes 20-40 cm well represented	
• Horizontal structure (% cover, gap length, stem density)	Openings in the direction of the fall-line <20 m >300 stems/ha >24 cm nurse logs in gaps	single trees large age variability 320 stems/ha >24 cm gaps with nurse logs			DBH classes >50 cm reduced >300 stems/ha >24 cm DBH	
• 'Backbone' trees (crown development, slenderness, target diameter)	>50% of the crowns uniform roots mostly well anchored only few leaning trees	many deformed crowns spruce not stable some leaning trees		remove strongly leaning and large trees	no large strongly leaning trees	
• Regeneration: seedbed	microsites safe from moving debris present, area with strongly competing ground vegetation <1/3	little competition from vegetation		leave down timber partly on site		
• Regeneration: small saplings (10-40 cm tall)	saplings in canopy gaps present	single saplings everywhere		create gaps 20 x 25 m establish browsing exclosure	small saplings under canopy on half the area, species mixture consistent with target (proportion of lime and maple >30%)	
• Regeneration: tall saplings (40 cm tall to 12 cm DBH)	>2 small clusters/ha (on average every 75 m) or cover >4%, species mixture consistent with target	few suppressed broad-leaved saplings			Tall saplings (>1.5 m) in openings species mixture consistent with target	

very bad minimal ideal

yes X no

5. Urgency small medium X high

6 Perspectives in the management of protection forests

During recent decades, research has made significant contributions to our understanding of protection forests and to science-based decision-making (FREHNER *et al.* 2005; ANGST in press). Knowledge has increased about tree–rockfall interactions (DORREN *et al.* 2004; SCHÖNENBERGER *et al.* 2005), the vulnerability of protection forests to windfall (DOBBERTIN 2002; MAYER *et al.* 2005) and bark beetles (GALL *et al.* 2003), the regeneration of mountain forests (BURSCHEL *et al.* 1985; AMMER 1996; BRANG 1998; REIF and PRZYBILLA 1998; DIACI *et al.* 2005), and forest restoration after disturbances (FISCHER 1998; HEURICH 2001; SCHÖNENBERGER 2002). Increasingly, simulation models and geographic information systems are used to generate long-term views on different scenarios of protection forest development (KUPFERSCHMID and BUGMANN 2005; WEHRLI *et al.* 2005; GRÊT-REGAMEY *et al.* submitted). Conceptual approaches for quantifying risks from natural hazards are also available (HEINIMANN *et al.* 1998).

However, many questions remain unresolved. For instance, it is still difficult to extrapolate results about forest dynamics gained on one site to others (BRANG *et al.* 2004). Also, the effects of forests in preventing snow avalanche release (MEYER-GRASS and SCHNEEBELI 1992; BERGER 1996), landslides (RICKLI *et al.* 2001) and floods (HEGG *et al.* 2005) require study. While existing simulation models of forest dynamics may be well-suited to handle forest renewal, stand growth, disturbances, silvicultural treatments, or browsing by ungulates in protection forests, or combinations of some of these factors, they are unable to handle the complex interplay between all these factors and processes. Finally, there is still a major lack in synthesizing existing knowledge in natural science, engineering, and economics. Integrated risk-based approaches are still rare (WILHELM 1999; BEBI *et al.* 2004).

Further research should be directed to reducing uncertainties in determining the risks involved with leaving protection forests unmanaged. This may enable an increased use of this management option. On the other hand, the reduction in uncertainty may also enable increased management of protection forests for other purposes such as conservation and timber harvesting, as a contribution to sustainable resource management.

For the time being, it is advisable to use a management approach that mainly utilizes, or contributes to, the restoration of natural ecosystem components, structures, and processes. The approach used in managing Swiss protection forests is clearly in line with this advice.

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Annex. Definitions of selected terms in protection forests.

Direct protection = a protective effect that is associated with the presence of a forest at a particular location

Disturbance = the sudden destruction of a single canopy tree, or of several canopy trees. This definition is narrower than the broad one that is sometimes used for disturbance: ‘Any relatively discrete event in time that disrupts ecosystem, community or population structure and changes resources, substrate availability or the physical environment’ (VAN DER MAAREL 1993).

Indirect protection = a protective effect that is associated with the presence of a certain portion of forest at the landscape level

Natural hazard = an abiotic natural factor that has the potential to cause damage to people or assets

Protection forest = a forest that has as its primary function the protection of people or assets against the impacts of natural hazards or adverse climate

Protective effect = an effect of a forest in preventing damage that natural hazards would otherwise cause to people or assets, or in mitigating such damage.

Protective function = a protective role that man attributes to a forest

Resilience (of a forest ecosystem) = the ability of the forest to recover from a disturbance

Resistance (of a forest ecosystem to disturbance) = the ability to resist disturbances without significant changes in ecosystem components, structures, and processes