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Protective Forests and Silvicultural Stability
An Example of Planning in the Aosta Valley

Protection is of vital importance to human populations and activities in the European Alps. In the short to medium term, failure to manage alpine protective forests leads to intolerable risks for people who live and make a living in alpine valleys. The most important features of a protective forest are its stability properties, that is, its ability to carry out its protective function reliably and continuously and, if this is achieved, its ability to maintain its structure and vitality in the face of internal and external influences. Since maintaining and improving stability properties is costly and labor intensive, the objective of interventions should be an acceptable—rather than an ideal—degree of stability in order to ensure the functions required of the protective forest over a 20–50 year period. Such interventions are collectively referred to as minimal tending. A case study of the Ban de Ville forest in Courmayeur (Aosta Valley, Italy) illustrates aspects of silvicultural planning. Only one third of the Ban de Ville forest was found to be acceptably stable. The main causes of instability were unsuitable species composition, simplified vertical structure and cover, presence of Ips typographus *and* Heterobasidion annosum, *and presence of high densities of wild ungulates. Measures to improve stability properties aimed to increase the presence of larch among a homogenous stand of Norway spruce and gradually establish a multilayered, small group structure.*

Keywords: *Silviculture; protective forests; mountain forests; stability; natural disturbances; minimal tending; stand structure; Aosta Valley; Italy.*

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Introduction

The issue of sustainability in silviculture has been the focus of much interest in the field of forestry over the last few years; it is particularly important in mountain forests. Mountains and uplands cover approximately one fifth of the Earth's surface. About one tenth of humankind lives in mountain regions, and they affect the lives of more than half of the world's population (Ives et al 1997). Mountain forests have drawn growing international attention, with many organizations and conferences acknowledging their importance over the last decade (Price 1998; Zingari 1998), starting with the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992 and the inclusion of Chapter 13 in Agenda 21. This was followed by the Strasbourg European ministerial conference and its ratification of Resolution S4 entitled "Adapting the management of mountain forests to new environmental conditions"; the Alpine convention signed by all the countries that share the European Alps; the Council of Europe Congress of Local and Regional Powers and its "European Charter of Mountain Regions"; and the recent Strasbourg, Helsinki, and Lisbon conferences, at which 25 European countries reaffirmed their willingness to reinforce their attention to and their efforts on behalf of conservation and sustainable management of mountain forests.

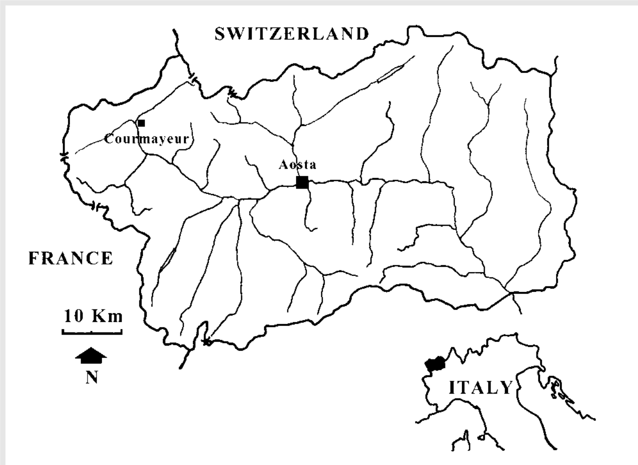
Past and present forest functions in the European Alps

If no forests existed in the Alps, human populations would not inhabit most valleys. Forests afford protection against avalanches, landslides, debris flows, and rock falls. They fix surface soil, prevent erosion, and play an essential role in water resource management at the watershed and local levels. They influence climate regulation and air quality. Human activity has radically transformed mountain forests in various ways: large forest areas have been destroyed, and the natural composition of forests has been modified through logging, thinning, and tending. Substantial economic and social changes in mountain areas over the past few decades have drastically modified forest use. Traditional forest functions have been abandoned while the importance of other functions has grown. At present the main functions of alpine forests are

- protection,
- tourism and recreation,
- wood production,
- landscape and nature conservation.

Protection is the most fundamental of all forest functions. Construction in previously nonurban areas, the growing importance of road systems, the need to maintain road and rail viability all year round, new industries, and winter tourism have greatly increased the requirements for protection. This is especially significant in the Aosta Valley watershed, where the average altitude is 2106 m asl with more than 80% of the territory lying above 1500 m asl (Figure 1). The protective function of the forest is particularly important here because of the area's structure and needs: traffic between the lateral valleys and the main valley of the Dora Baltea River needs to be maintained all year round. Tourism is the region's main resource, constituting about 40% of the region's income and employing more than 12,000 people.

FIGURE 1 Location of the Aosta Valley and the study site.



As local regulations in the Aosta Valley Alps dating back to the 13th century reveal, mountain people have long been aware of the function of forests in stabilizing slopes and limiting damage from extreme events. The oldest written evidence for protective forests in the Alps is found in documents that date back to 1333 and 1480, referring to forests above dwellings (Gerbore 1997). Despite protest from local populations and mining and military enterprises, wide-ranging decrees severely limiting the use of a great number of woods were issued between the 14th and 17th centuries. The *Coutumier du Duché d'Aoste,* a written collection of Aosta Valley norms and customs issued in 1587 by Carlo Emanuele I of Savoy, reiterates the ban on wood cutting in protective forests (*bois bannis*). The same norm is referred to in an edict dated April 1757 concerning the use and conservation of forests in the Valle D'Aosta. Numerous forests still have names that reflect their historic function: *Bois de ban* (Sarre, Fenis, Courmayeur, Aymaville), *Bois de sauvegarde* (Saint-Rhémy-en-Bosses), and *Bannwoald* (Gressoney Saint-Jean).

For centuries, the only conservation measure in these forests consisted of a ban on logging. Landolt already recognized the need for a specific silvicultural strategy for protective forests in 1862 (Ott 1978): "in the long run we may be faced increasingly with overmaturity problems if we do not prevent this danger promptly and permanently." Despite the great interest in alpine forests shown by many institutions in the past few decades, silvicultural interventions have not been effective enough and most protective forests in the Alps are affected by major problems (Mayer 1982), including

- a marked lack of regeneration,
- a scarcity of medium-aged trees,
- insufficient stability, and
- increasing vulnerability to natural disturbances.

Definition of the protective forest

All forests have a general protective role, but there are substantial differences between protective functions. Some forests have a generic protective role, contributing to surface soil conservation, watershed management, and air quality. Other forests have a specifically human-related role in protecting people, buildings, road and rail traffic, and power supply from natural hazards such as avalanches, rockfalls, landslides, erosion, and floods. Such forests have a direct protective function (Schönenberger 1998).

The direct protective role of forests needs to be efficiently and continuously effective. It is indispensable to prevent destructive logging in protective forests and to ensure that they are not abandoned to their natural course of evolution because forest stands left completely to themselves are highly susceptible to destructive events during certain phases of their natural development. Forests with a direct protective function should therefore be a high priority for silvicultural intervention and should definitely not be abandoned (Motta 1998).

Stability properties of protective forests

Forest ecology and stability

The term stability is widely used in forest ecology, but there is no generally accepted definition of what stability is. In order to avoid confusion and misunderstanding, Grimm and Wissel (1997) proposed replacing the term stability by the following stability properties: constancy (staying essentially unchanged), resilience (returning to the reference state after a temporary disturbance), and persistence (persistence through time in an ecological system). Other stability properties vital in a protective forest are resistance (an aspect of constancy, that is, staying essentially unchanged despite the presence of disturbance) and elasticity (an aspect of resilience, ie, the speed of a return to the reference state after a temporary disturbance). Silvicultural planning of a protective forest aims to assess the forest's stability properties and study stability mechanisms (mechanisms responsible for stability properties).

No living object is ever constant; individuals, populations and communities always change. As in all forest ecosystems, the structural and functional characteristics of mountain forests change continually. Structural modifications can be slow, such as the growth of trees, or rapid, as when trees are destroyed by a windstorm. But all should be seen as part of a cyclical succession of events at different phases of evolution, starting with the genesis of the forest and ending with its disintegration.

In the absence of anthropogenic disturbances and climate change, a mountain forest ecosystem is stable. Stability is a property of the whole system and allows it to go on, but its significance is strongly related to time, scale, and pattern (Levin 1992; Peterson et al 1998) since different structures and species succeed each other on each surface unit. The stability properties of a whole forest must therefore not be confused with the stability properties of single stands since the periodic destruction of single stands is a normal part of the forest life cycle. This natural cyclicality is incompatible with the functions of the protective forest since the natural life cycle of a forest includes periods in which the forest cover is not sufficient to guarantee the degree of protection required for human activities and buildings as well as periods when forest cover is absent (Figure 2). In the absence of human activity, the destruction of forest stands is due to natural disturbances (Pickett et al 1989), defined as any relatively discrete event that changes the structure of the ecosystem, the community, or the population and hence modifies the physical and functional characteristics of the system. Natural disturbances can be characterized by frequency (eg, the number of times they occur in a century) and by intensity. Harper (1977) subdivides destructive events into disasters and catastrophes. He defines a disaster as an event occurring more often than once in the average lifetime of a forest generation.

The tree species constituting mountain forests are long lived, and in conjunction with the frequency of disasters, this means that protective forests must have a degree of resistance such that disasters cause the least possible damage. The possibility of a catastrophe occurring and destroying the entire forest stand, whatever its degree of resistance, cannot be excluded, however, and

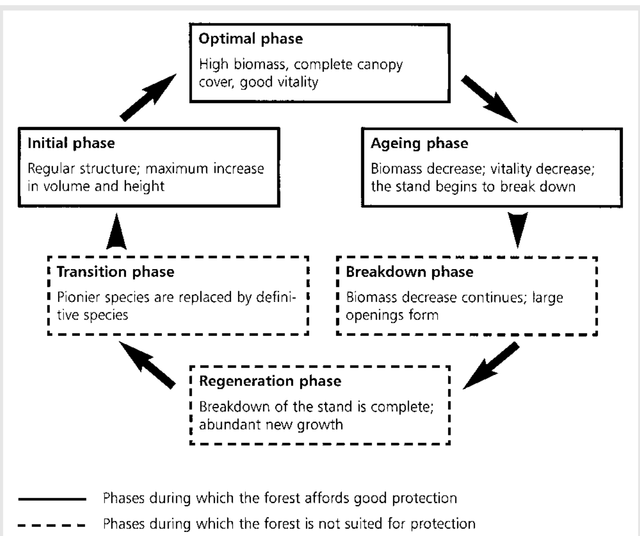


FIGURE 2 Schematic representation of forest dynamics without anthropogenic influences. Natural dynamics are a problem in a protective forest because not all phases afford good protection.

there is no way to ensure the survival of a stand in an event of such intensity. As long as a forest has a high degree of resistance, it can afford good protection against disasters but may be completely inadequate in the event of a catastrophe. In order to face a catastrophe successfully, a forest must be very resilient and elastic, that is, be able to recover rapidly following destruction.

Silviculture and stability

From a silvicultural point of view, the stability of a stand in protective forests can be defined as its ability to carry out its functions reliably and continuously and, once this is achieved, to maintain its structure and vitality in the face of internal and external influences. In stands whose function is primarily protective, the properties of constancy, resilience, persistence, resistance, and elasticity are of fundamental importance. The management of forest stands is tantamount to the maintenance and improvement of these stability properties at the level not of individual stands but of the whole forest in order to maintain or restore the reference system (Jax et al 1998). Taking into account a forest's natural dynamics, foresters must maintain the forest's structural ability to give protection and stop natural evolution at the phases that ensure the highest degree of stability. The means used to achieve these goals are silvicultural interventions.

Every forest stand is characterized by a different degree of vulnerability to disturbances (Quine et al 1995). This depends on permanent factors (eg, the characteristics of the site) as well as on progressive factors (eg, those due to tree growth) and episodic factors (eg, those occurring during the period immediately following thinning). Silviculture can have a direct impact only on some characteristics of the forest ecosystem. Among those most relevant for stability are the number of species and their relative importance and the vertical and horizontal structure, or texture, of the stand. Since maintaining and improving stability properties is costly and labor intensive, an acceptable, rather than ideal, degree of stability should be aimed at to ensure the functions required of the protective forest over the following 20–50 years. Operations that aim to achieve this minimum degree of stability are collectively referred to as "minimal tending of protective forests" (Wasser et al 1996).

Case study: the Ban de Ville Forest in Courmayeur

Site description

The Ban de Ville forest in the Courmayeur municipality (Figure 3) faces west and extends over 143 ha at a height between 1300 and 2300 m asl. This forest is owned by the municipality and has always been an important resource for the local inhabitants in terms of wood production, grazing of livestock, and, above

FIGURE 3 The Ban de Ville forest above Courmayeur. (Photo by J.C. Haudemand)

TABLE 1 Criteria used in describing forest stand suitability for protectiveness and silvicultural stability.

Category	Criteria
Stand history	Origin Past silvicultural treatment Evidence of natural disturbances
Stand structure	Vertical structure (layering) Horizontal structure (texture) Density
Dominant trees	Species Height/diameter ratio Crown depth Root system Vitality (crown transparency) Damage and diseases
Natural regeneration	Quantity, vitality, and species Seedbed and soil suitability for regeneration Competition between forbs and shrubs on the ground Impact of ungulates

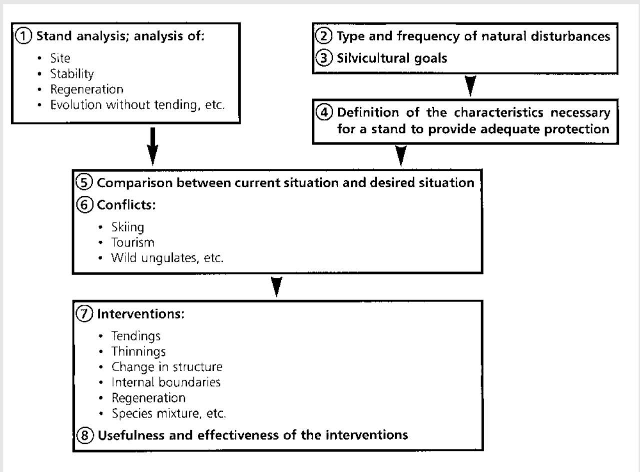
all, protection of the village from avalanches. The most prominent tree species is the Norway spruce. Larch (*Larix decidua* Mill) is predominant above 2100 m asl; it is also present in the natural and artificial clearings throughout the wooded areas and in a few areas of artificial afforestation lower down. There are four main forest types (IPLA 1997): typical mountain-level Norway spruce stands (dominant in the lower part of the forest), typical subalpine-level Norway spruce stands (dominant in the upper part of the forest), larch with *Rhododendron ferrugineum* and *Vaccinium myrtillus* (at the upper forest limits), and larch with forbs (in the sites with high snow accumulation and near avalanche torrents).

Methods

The first step was to identify single forest stands, that is, the parts of the forest with a uniform density, structure, and composition. This was done by analyzing aerial photographs and subsequently checking the boundaries of each unit in the field. A forest map was then elaborated using GIS, and each stand was characterized according to forest type, aspect, slope, surface, structure, and minimum and maximum elevation. The suitability of each stand for protection, that is, the effectiveness of its stability properties, was analyzed according to 16 criteria (Table 1). Each criterion was judged on a scale of 1 to 4, with 1 indicating a stand suitable for protection that is stable, 2 indicating a stand suitable for protection but that is partially unstable, 3 indicating a stand partially suitable for protection that is unstable, and 4 indicating a stand unsuitable for protection or partially suitable for protection that is seriously unstable (Ott and Schönbächler 1986). A weighted index value from 1 to 4 was then assigned to each stand in order to underline which criteria were thought to have the greatest influence under local conditions. Finally, the current stability properties of the stand were compared with the targeted stability properties, that is, those that would potentially afford effective protection for a number of decades.

The target structure of a stand was defined according to forest type, elevation, and position of the stand, along with the aspect, type, frequency, and intensity of natural disturbances, what the stand needs to protect against, and the types of danger it is exposed to. Stands defined as protection against avalanches (Fiebiger 1978; Ott 1996) need to have a composition and structural characteristics different from those that are necessary for protection against rockfalls. The targeted structure consists of the minimum, not the ideal, conditions of composition, structure, and density that will allow the

FIGURE 4 Example of an operative procedure for planning minimal tending measures in protective forests.



forest to carry out its protective function for a reasonable period of time. Silvicultural interventions must be designed to reduce the extent of the damage caused by a disturbance as well as the duration of the effects of the disturbance and the probability of damage occurring.

Uneven and multilayered stands with a mosaic of all sizes and age classes are the best suited for protection (Campell et al 1955; Trepp 1981; Chauvin et al 1994; Frey 1994; Ott et al 1997). Such stands are also the long-term objective in the study area. In Norway spruce forests, the presence of larch is fundamental (Crosignani and Mazzucchi 1996). As far as regeneration is concerned, it is important to check for damage caused by wild ungulates, now the most significant threat to medium- to long-term stability in European alpine forests (Eiberle and Nigg 1987; Motta 1996).

Decisions regarding what interventions need to be carried out are made on the basis of a comparison between current and planned protection status. When it is established that the actual protection status is lower than the planned protection status, the first step is to evaluate whether the natural evolution of the forest will improve or decrease protection. In the case of this study, this was evaluated for the short term (10–15 years) and the medium term (50 years). The second step is to evaluate whether any of the existing silvicultural measures would improve the stability properties of the tree population. Some aged populations are so unstable that no silvicultural measure would be adequate. Third, a rough analysis of the costs of an intervention along with a cost-benefit analysis must be made in order to decide whether a modest or good improvement can be made at a reasonable cost, that is, in proportion to the importance of the objective to be reached. Finally, possible conflicts should be foreseen before interventions are decided on (Figure 4).

Results and discussion

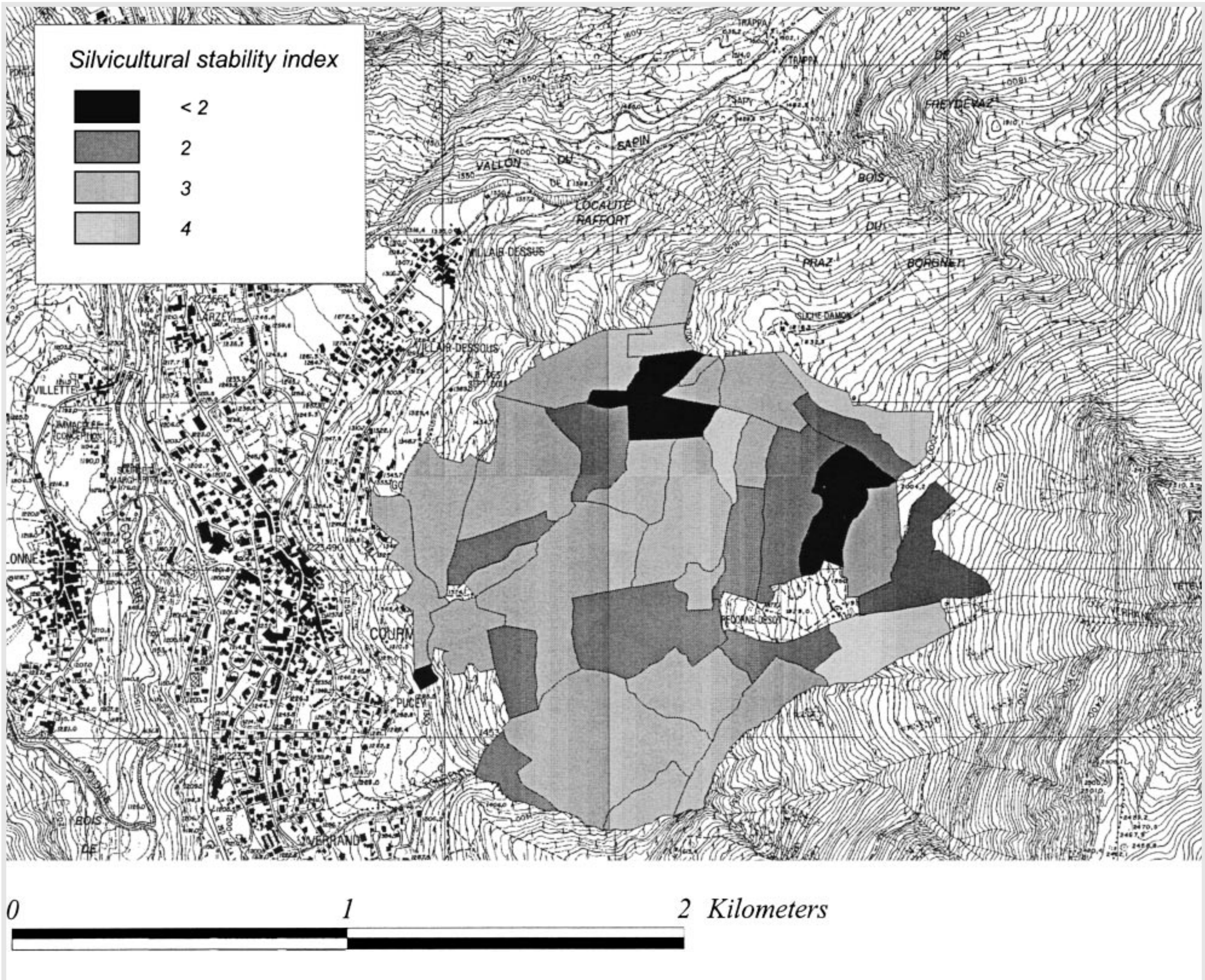
Thirty-seven different stands were identified in the Ban de Ville forest (Table 2). Overall, less than a third of the forest was found to have a structure suited for protection (Figure 5; Table 3). The main causes of instability detected by the study were unsuitable species composition, simplified texture and vertical structure, a lack of natural regeneration, the presence of *Ips typographus* (Pellissier 1997) and *Heterobasidion annosum,* and the presence of wild ungulates, including chamois (*Rupicapra rupicapra* L), roe deer (*Capreolus capreolus* L), and red deer (*Cervus elaphus* L). At present, these ungulates seem to have a limited impact on the forest's capacity to regenerate. They feed mainly on the most palatable species such as rowan (*Sorbus aucuparia* L) and rather little on Norway spruce and larch in most of the stands. However, the impact of ungulates is already influencing the future dynamic of individual stands. If wild ungulate populations increase, natural regeneration will be completely prevented (Motta 1999).

In the lower part of the forest, silvicultural interventions were carried out in the summer of 1998 by the Aosta Valley Regional Forestry Administration. They aimed to improve stability properties, to increase the forest's attractiveness for recreation, and to improve the quality of the trees in the stands capable of producing timber. The upper part of the forest is far from harvest roads and the silvicultural measures required are minimal tendings. The highest priority for intervention goes to stands with an index of 2–3; intervention is not necessary in those with an index of 1, whereas in those with an index of 4, interventions would be costly and their

TABLE 2 Structure types in the Ban de Ville forest.

Structure type	Number of stands	Surface (ha)	% of total surface
Multilayered, groups	12	46.4	28.5
Partially multilayered, groups not well defined	12	46.8	28.7
Uniform and monolayered	9	43.9	27.0
Open stands	3	6.3	3.8
Heterogeneous stands	2	19.6	12.0

FIGURE 5 Silvicultural stability index map of the Ban de Ville forest.



outcome uncertain. Using these criteria, 35 ha of forest were located for the first silvicultural intervention, the main purposes of which were defined as follows: to improve the presence of larch (15 ha), to increase the density of natural regeneration (18 ha), and to modify the forest structure (11 ha). A further measure is artificial afforestation in small groups of 3 ha (Schönenberger et al 1990).

The measures for silvicultural tending proposed are the following:

TABLE 3 Stability classes in the Ban de Ville forest.

Stability class		Number of stands	Surface (ha)	% of total surface
1–2	Suitable for protection but partially unstable	15	54.7	33.6
3	Partially suitable for protection and unstable	19	95.9	58.8
4	Unsuitable for protection or partially suitable for protection and seriously unstable	4	11.8	7.6

1. Species composition: favoring the presence of larch through the small-group selection method (Ott et al 1997) in order to improve resistance, with limited areas of small-group afforestation (Schönenberger et al 1990).
2. Vertical and horizontal structure (texture): transforming the monolayered stands (which are physically unstable and costly to maintain) into multilayered stands. The first intervention involves the creation or enhancement of internal boundaries by edge clearcuts or by opening long elongated clearings diagonally with respect to the line of steepest incline.
3. Regeneration
   – In areas where there are small groups of natural regeneration, single or small-group selection to favor the development of young trees. The trees to be harvested will be selected with the help of a sun compass (Schütz and Brang 1998) in order to obtain the best results and minimize destabilization of the forest stand.
   – In areas where there is no regeneration and where the tree stand is almost mature and even-aged, long, elongated clearings are also selected with the use of a sun compass to stimulate natural regeneration. These openings will have to be large enough to allow the establishment and growth of regeneration but small enough to prevent excessive spread of herbaceous and shrub species (Ott et al 1991). Care must also be taken not to orient them along the line of steepest incline in order to avoid detachment of avalanches. Trees harvested will be removed after all of these interventions because of the widespread presence of *Ips typographus* in the Ban de Ville forest.

Conclusions

The functions fulfilled by mountain forests have changed radically in recent decades: some traditional functions have become obsolete while the importance of others has grown. Because of the current population density and pattern of land use in the European Alps, protection is now considered one of the most important functions of mountain forests. Without active management, mountain forests cannot fulfill their protective role in a sustained way.

The costs of silvicultural tending to maintain forest protectivity are high for public institutions. Such tending should therefore only be carried out where the forest protects human activities and infrastructures. In these areas, the risks to people, structures, and activities as a result of a forest's failure to protect against avalanches must be carefully evaluated. Because they are costly, silvicultural interventions should aim to attain a minimally acceptable, rather than an ideal, level of protection. The time range should be 20–50 years. The stands most suited for the function of protection are uneven-aged, multilayered stands with a small-group horizontal structure. Composition is also of great importance, and the amount of larch should be kept down, especially in forests dominated by Norway spruce. As the case study of the Ban de Ville forest in Courmayeur has shown, unsuitable species composition, too simple texture with an essentially vertical structure, lack of natural regeneration, the presence of *Ips typographus* and *Heterobasidion annosum,* and the presence of wild ungulates can constitute a serious menace for a protective forest. Apart from importing species composition and introducing and maintaining a small proportion of larch in pure Norway spruce stands, the interventions chosen to improve stability in the study area aimed to gradually transform the present structure into a small-group, multilayered forest structure.

The transformation of regular stands into small, multilayered stands is a key issue in all the subalpine forest in the Alps. Nevertheless, the definition of appropriate silvicultural strategies requires awareness of local environmental conditions, past uses of the forest, past human and natural disturbances, and the ecological and physiological requirements of individual species. Every forest stand is unique in time and space; it is necessary to proceed with due caution when transferring knowledge and experience acquired through study of one stand to other alpine forest environments.

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