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Abstract

Ecosystem management of protection forests aims at maintaining forests near a state during which effective protection is secured. As the evolution of a dynamic forest ecosystem cannot be stopped, silvicultural measures are required which aim at maintaining both the ecosystem integrity and the protective function of mountain forests. Ecosystem integrity is defined as the system's capacity to maintain structure and ecosystem functions using processes and elements characteristic for its ecoregion. Here, ecosystem functions also reflect the capability of the ecosystem to provide functions of value to humans. Ecosystem integrity of a protection forest implies that the stability of the forest is high, because that is required to provide a high level of protection in the long term. The main conditions promoting natural evolutionary processes and ecological stability in protection forests are 1) a diverse composition of species, 2) sufficient natural regeneration and 3) an optimal forest structure. The first example in this chapter explains how these conditions might be achieved by silvicultural interventions in a forest that mainly protects against rockfall in the Austrian Alps. The second example deals with socio-economic aspects of ecosystem integrity of a forest that also protects against rockfall, but then in the French Alps. Both examples show that forest authorities are aware of techniques to improve the stand stability of protection forests, but the problem is that current forest management is often a kind of trial and error, because the exact consequences of interventions for forest ecosystem dynamics are not known. Therefore, it is proposed that forest ecosystem research should shift focus from protection forest dynamics to the geosystem functioning of protection forests, including the effects of natural and human disturbances. For this, the concept of panarchy may be a promising way forward.

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2.1 Introduction

The ultimate goal of ecosystem(-based) management could be summarised as 'the preservation of ecosystem integrity while satisfying human needs' (Grumbine, 1997; Yaffee, 1998; Pirot et al., 2000). Integrity in relation to ecosystems was first mentioned by Aldo Leopold who stated 'a thing is right when it tends to preserve integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise' (Leopold, 1949).

Current ecosystem management of forests is mainly based on ecological stability in relation to disturbances. Here, stability is often, for simplicity, characterised by the two components resistance and resilience, or synonyms of these terms (Holling, 1973; Grimm et al., 1992; Larsen, 1995; Führer, 2000; Kräuchi et al., 2000; Motta and Haudemand, 2000; Brang, 2001). Increased knowledge of ecological stability in relation to disturbances and increasing labour costs resulted in a paradigm shift from forest management for timber production towards forest ecosystem management (Attiwill, 1994; Führer, 2000; Harvey et al., 2002), especially in case of management of forests that protect against natural hazards (Larsen, 1995; Brang et al., 2000; Kräuchi et al., 2000; Motta and Haudemand, 2000; Bebi et al., 2001; Brang, 2001). Parallel, it has been discussed whether forest management is necessary at all for ensuring the protective function of a mountain forest on the long term. This argument originates from the view that mountain forests are self-organising stable ecosystems (see Weiss, 2000). Yet, an increasing group of authors report that mountain forests could only fulfil their protective function on the long term if they are managed actively, since instability problems caused by overmaturity arise if silvicultural interventions are absent (Ott, 1978; Ott and Schönbächler, 1986; Führer, 2000; Kräuchi et al, 2000; Motta and Haudemand, 2000; Brang, 2001).

More 'close-to-nature' silvicultural techniques, in comparison to those applied for traditional management of timber production forests, are increasingly applied. Current examples of such methods include minimal tending and the use of stand structural types (Wasser and Frehner, 1996; Motta and Haudemand, 2000; Brang, 2001). The aim of such 'close-to-nature' silvicultural interventions in protection forests is to maintain forest stands in a stage during which effective protection is provided (Motta and Haudemand, 2000). This instantly indicates the main problem of managing protection forests, as it is impossible to stop the evolution of a forest. Therefore silvicultural measures are required, which are associated with the trend of development of the forest ecosystem and which aim at maintaining the integrity of the protection forest ecosystem. To achieve this, knowledge of ecosystem
integrity of protection forests is needed. Consequently, the objective of this article is to explain the concept of ecosystem integrity with respect to protection forests and to describe how this concept could be integrated in management of protection forests. Two examples dealing with silvicultural and socio-economic aspects of ecosystem integrity of protection forests in the European Alps will be presented. Subsequently, some research needs will be discussed in order to improve ecosystem management of protection forests.

2.2 Protection forest: function and dynamics

First of all, a short description of protection forests as defined in most alpine countries in Europe will be given, since the term is often used for forests with different functions (Ottitsch and Weiss, 2000). A protection forest has mainly an object-protection or direct protective function (Schönenberger, 2000). At the same time such a forest provides a site-protection function, which is actually a prerequisite for the direct protective function (van Noord, 1996). In addition, like all mountain forests, protection forests provide multiple functions, such as recreation, sequestration of carbon dioxide and conservation of biodiversity (Buttoud, 2000; Cattai et al., 2000; Führer, 2000).

The direct-protective function of a forest implies that the forest directly protects people, buildings and infrastructure against the impact of natural hazards such as snow avalanches and rockfall (Brang, 2001). The site-protection function is important as a forest stand needs to protect its site against processes such as excessive soil erosion and the occurrence of debris flows (Rey and Chauvin, 2001). If the site-protection function is impaired, the forest site erodes, which results in a loss of the forest ecosystem as a whole.

Mountain forests are self-organising stable ecosystems if regarded at a landscape scale, which normally do not need any silvicultural intervention for their continued existence. But people want to utilize timber as a sustainable resource and therefore need to manage forests. Furthermore, some forests have become degraded as a result of over-harvesting, heavy ungulate browsing or livestock grazing and need to be managed in order to fulfil the protective function. This means that some forests can be left untouched, others can be managed and some need to be managed.

Mountain forest stands constantly evolve from a regeneration phase to an optimal phase and back again, as illustrated in Figure 2.1. During the transition phases in between the forest structure develops or breaks down. As a consequence the protective function is minimal during those phases (Motta and Haudemand, 2000), which is also indicated in Figure 2.1.
The rate of transition into a next phase is not only determined by growth or ageing of individual trees, but also by the effect of disturbances on the forest ecosystem (Attiwill, 1994; Peterson et al., 2000). A disturbance is a natural or human-induced discrete event in time or space that changes physical (biotic and/or a-biotic) conditions of an ecosystem (after White and Picket, 1985). The effect of a disturbance is determined by its magnitude and by the ecological stability of the forest stand. Stability might differ a lot within a stand due to variation in stand factors such as micro-site conditions like availability of nutrients, soil moisture and light (Schönenberger, 2000). Therefore, several development phases presented in Figure 2.1 may occur simultaneously within a stand. A disturbance might be ‘normal’ for an ecosystem. Natural disturbances in mountain forests such as snow avalanches or rockfall are important processes since they drive development and change. By doing so, these processes partly determine the integrity of a mountain forest ecosystem.

2.3 Forest ecosystem integrity

Theoretically, a mountain forest that goes through developmental phases without human disturbances may be considered as a natural forest ecosystem. The integrity of such an ecosystem is not necessarily high, because that is determined by the definition of ecosystem integrity. Many scientists discussed ecosystem integrity, especially the last decade (see Karr, 1990; Noss, 1990; Kay, 1991; Woodley et al., 1993; Westra, 1996; De Leo and Levin, 1997; Goldstein, 1998; Müller et al., 2000). Nevertheless, there is still no agreement on a uniform definition. Here, ecosystem integrity is defined as the system’s capacity to maintain structure...
and ecosystem functions using processes and elements characteristic for its ecoregion. Here, ecosystem functions do not only refer to relations and processes that are inherently part of a dynamic, open and complex ecosystem (Pimm, 1984; O’Neill et al., 1986). Ecosystem functions also reflect the capability of the ecosystem to support services or functions of value to humans (De Leo and Levin, 1997), such as regulation functions, habitat functions, production functions and information functions (after de Groot, 1992). A protection forest is a good example of an ecosystem performing a regulation function.

Since the definition given above links ecosystem integrity to functions of value to humans, a protection forest ecosystem with a high integrity implies that the stability of the forest is also high, because that is required to provide a high level of protection in the long term. This does not account for a forest without a protective function, since the ecosystem integrity of a forest in a breakdown phase might be high, but the stability is low. A protection forest needs both ecological integrity and stability, since both determine its ecosystem integrity. Ecological integrity is needed to maintain variability in structure and functions; stability is needed to maintain the variability within a critical range. This is essential to avoid perturbation to a state in which the protective function is minimal. Here, perturbation is the change of motion, course, arrangement or structure of a whole ecosystem, caused by disturbances (after White and Picket, 1985).

2.4 Ecosystem management of protection forests

Within an ecosystem, functions exist which are essential for maintaining its organization in the face of disturbances. An ecosystem is only capable of providing functions of value to humans if these essential functions are fulfilled. Therefore, the primary objective of management strategies is to protect, maintain and/or restore the essential ecosystem functions of forest ecosystems using processes and elements characteristic for its ecoregion (Andersson et al., 2000). Subsequently, ecological integrity and stability with respect to a function of value to humans could be promoted to obtain a high ecosystem integrity.

The main problem with protection forest management is to predict the trend of development of a forest in the face of disturbances, which could be both human and natural, but especially the natural disturbance the forest should protect against. This relatively unknown factor in combination with the given fact that an ecosystem is an open, dynamic system, endorses the general rule stated by Holling and Meffe (1996) that ecosystem management should not aim at preserving something that must change. Consequently, forest
ecosystem dynamics must be integrated into management strategies (Attwill, 1994). Current management of protection forests mainly tends to preserve stand stability, but the aim should be to create or maintain conditions that promote evolutionary processes while maintaining forest ecosystem integrity in relation to its assigned function. Figure 2.2 shows that, before silvicultural measures are planned and executed, two important questions need to be answered. The first question is whether the ecological integrity of the protection forest is high. If this is the case, the second question is whether the ecological stability is high. If one of these conditions is not fulfilled, measures could be taken, if considered appropriate, as shown in Figure 2.2.

![Flow chart](image)

**Primary objective:**
maintain protective function of forest

Is the ecological integrity of the forest high?

- **YES**
- **NO**

Is the ecological stability high enough to sustain protection?

- **YES**
- **NO**

Monitoring forest ecosystem development

If necessary, backup protection by technical constructions
Silvicultural measures to increase integrity

Can silvicultural measures increase stability while maintaining integrity?

- **YES**
- **NO**

Protection by technical constructions

Figure 2.2. Flow chart presenting essential steps in determining a management plan for protection forests. Solid arrows indicate direct actions to be taken or questions to be answered and dotted arrows indicate an intermediate time period of several years to decades.

### 2.5 Towards implementation

Conditions promoting natural evolutionary processes and ecological stability in protection forests could be categorized in three practical and general criteria (modified from Motta and Haudemand, 2000):

1. Diverse composition of species
2. Sufficient natural regeneration
3. Optimal forest structure
But before these criteria are evaluated to estimate the ecosystem integrity of a protection forest, its history must be assessed. The origin of the forest, past silvicultural treatments and evidences of natural disturbances must be known (Motta and Haudemand, 2000). The further management starts from the state defined by the criteria mentioned above, the stronger the management intervention must be (Führer, 2000), but preferably silvicultural intervention mimics small-scale natural disturbances (Bengtsson et al., 2000). If ecosystem dynamics tend to deviate from the course directed to fulfilment of the criteria, the suitability of the forest stand for performing a protective function might be questioned. Other protective measures, like technical constructions, might be required in such a case, since management cannot push a forest ecosystem in a direction opposite to the natural one.

The composition of species should be characteristic for the ecoregion and if possible diverse (both for the trees and the understory vegetation). Diversity determines the amount of variability in the potential drivers of an ecosystem (Holling and Meffe, 1996), which are the key species and key processes in an ecosystem. It is still unclear whether a diverse composition of species increases ecosystem stability (Holling, 1973; May, 1973; Tilman and Downing, 1994; De Leo and Levin, 1997; Tilman et al., 1997; Bengtsson et al., 2000). However, there is much evidence that mixed forests are more resistant to perturbations and more resilient after disturbances than monocultures. They also perform ecosystem functions more reliable over time (Larsen, 1995; Bengtsson et al., 2000).

Natural regeneration is equally important as the species composition, because it is the primary source for natural stand renewal. Therefore, the maintenance of a good seedling bank is required, but sufficient light, prevention of competing ground vegetation suppressing seedlings, prevention of heavy browsing by ungulates as well as suitable seedbeds are also important (Ammer, 1996; Motta, 1996; Ott et al., 1997; Fuller and Gill, 2001). Tree stems lying on the slope surface provide both good protection against rockfall and snow avalanches and they provide good seedbeds. Therefore, timber should be left in the stand unless it is too risky with respect to bark beetle infestation (Kräuchi et al., 2000).

The optimal structure of a protection forest depends on the type of natural hazards the forest should protect against. For example, a forest protecting against rockfall should have a large number of trees, preferably with thick tree stems near the rockfall source area (Wasser and Frehner, 1996). At the same time a multilayered stand is needed to ensure this protective function on the long term. In the accumulation zone of a rockfall slope, a forest consisting of dense bushes and shrubs is needed (Mani and Kläy, 1992; Gsteiger, 1993).
Generally, uneven multilayered stands with a mosaic of all sizes and age classes are the best suited for protection (Ott et al., 1997; Kräuchi et al., 2000; Motta and Haudemand, 2000). This general structure should be aimed for since protection forests mostly protect against several types of natural hazards. The cluster structure characteristic for high-elevation stands may serve as a model for the arrangement of seedlings in plantations and for silvicultural interventions in homogeneous stands aiming at the optimal structure for protection (Schönenberger, 2001b).

Ideally, a forest ecosystem that fulfils the three general criteria mentioned above enters a ‘steady-state’ in which small patches with alternating developmental phases provide a collective stability for the stand or forest (see Fig. 2.3). Führer (2000) assumes that in this state efficient mechanisms of self-regulating processes control all destabilising forces, thus keeping the destructive phases temporally and spatially within ecologically tolerable limits, which is sub-optimal for protection on the short term, but as optimal as possible on the long term.

Fig. 2.3. A sub-optimal protective function could be maintained by small patches in phase-shifted developmental states, which build up a collective stability for the forest stand. This approach requires that similar phases of patch dynamics are not occurring synchronically, e.g. all the patches being in a breakdown phase.

2.6 Example 1: a silvicultural/forest ecological case

The ‘Außerbacher’ forest covers about 50 hectares on a south-southwest facing slope in the Montafon region in Austria (between 47°8’ and 46°50’ latitude and 9°41’ and 10°9’ longitude). The forest stretches from the valley floor, which is situated at 930 m above sea level (a.s.l.), up to 1500 m a.s.l. and grows on a uniformly shaped talus slope with an average inclination of 39°. Because of its proximity to the Außerbach hamlet this forest has always been an important resource for local inhabitants in terms of wood production and grazing livestock. Above all, the forest protects the Außerbach hamlet against rockfall, which originates from a
cliff face, with a height up to 100 m, in the upper part of the forest hillslope. In addition, the forest prevents the release of snow avalanches on the steep parts of the hillslope.

In 1988 the protective function of the forest reached a critical level because firstly most of the trees had been damaged by rockfall while substantial regeneration was lacking and secondly, the forest was prone to windthrow. The latter had already caused gaps in the lower parts of the forest. These had been widened by a subsequent bark-beetle invasion (see Fig. 2.4, situation 1988) as its initial vulnerability due to the high proportion of spruce and the sun-exposed location, was increased. It seemed that the ecological processes could not sustain the protective function of the forest at that time. As a result, ecosystem integrity could not be maintained anymore. Therefore, the local forest authority initiated a rehabilitation project, which started with assessing the history of human and natural disturbances in the forest.

Until 1960, up to 300 sheep grazed in the Außerbacher forest during the months May, June and October. As sheep have a selective feeding behaviour, natural regeneration of deciduous trees and shrubs in particular, was suppressed. This had a long-term effect on the species composition of the forest. Indicative is that the present coverage of Beech (*Fagus sylvatica*), is not more than 10%, although the potential natural forest community up to an altitude of 1050 m corresponds to a Beech-dominated *Luzulo Fagetum*. After 1960, two feeding stations for deer and roe deer were installed on the footslope of the Außerbacher forest, which then served as a winter habitat for ungulates for over two decades. The increased ungulate population resulted in an enormous browsing pressure, which was identified as the main cause for the lack of natural regeneration. In addition to the direct and indirect human interference there has been a permanent impact of natural disturbances such as rockfall, snow avalanches and wind, of which rockfall has always been the most dominant disturbing agent in the Außerbacher forest.

The ideal structure of a protection forest, mainly composed of the tree density, the diameter distribution as well as the gap size and the vertical layering, depends on the type of natural hazard the forest should protect against. According to Wasser and Frehner (1996) the number of trees per hectare in a rockfall protection forest should be higher than 400 with stem diameters at breast height (DBH) larger than 40 cm. Gaps in the forest should not exceed a length of 20 m in the direction of the slope.

According to the forest inventory of 1988, during which all the developmental phases of the forest were mapped using Leibundgut (1959), about 84% of all the trees in the Außerbacher forest were damaged by rockfall (Stand Montafon, 1990). About 45% of the total forest area was in a so-called ageing phase (Fig. 2.4), which was amongst others
indicated by a low tree density of 290 trees per hectare. At first sight these stands appeared stable against windthrow because of the varying horizontal and vertical structure and a well-distributed network of vital long-crowned skeleton trees (in German: Gerüstbäume, being trees with a stabilising function). But the high percentage of trees with heart rot reduced this apparent resistance. Crucial for the prospective stand development was the lack of regeneration, which would have led to stand disintegration and consequently even lower tree densities. This would have considerably reduced the resilience of the forest in the long term.

Figure 2.4. Distribution of developmental phases, disturbances and silvicultural measures

Twenty-two percent of the forest was identified as being in an optimal phase in terms of stand development and had an average number of 560 trees per hectare, which is in line with the guidelines of Wasser and Frehner (1996). These forest stands were spruce-dominated and mainly structured in homogeneous single-layers, which were most likely a result of the human
impact. It was to be expected that this homogeneous structure would not change in the future. In combination with high coefficients of slenderness (length/width ratio), short crown lengths and the high degree of rockfall-damaged trees, the threat of windthrow would increase in these stands. Only 19% of the area could be classified as a so-called selection forest with a multilayered structure and a mosaic of ageing, breakdown and regeneration phases. This type of forest grows mainly on steep rocky and blocky sites, which are hardly accessible for silvicultural interventions. Because of snow gliding, intensive rockfall and the browsing pressure some of the primary rockfall channels and gullies were denuded of trees (unstocked forest land). These areas accounted for 14% of the total forest land. It would be impossible to achieve regeneration without a reduction of the browsing pressure of ungulates and the construction of avalanche barriers in these areas.

On the basis of all the previously described information, the local forest authority regarded a) the reduction of ungulate population, b) the improvement of the accessibility via forest roads and c) the construction of avalanche barriers and rockfall nets in the major gully as urgent. These measures were a prerequisite for the implementation of the following silvicultural measures:

- small-scale felling with on-site deposition of trees diagonal to the slope,
- narrow irregular stripe felling by means of cable cranes all arranged diagonal to the slope direction,
- reaforestation of unstocked forest land and coppicing hazel to stimulate its growth.

These measures aimed at achieving the optimal stand conditions with respect to protection against rockfall, being a high tree density and thick tree stems, as described by Wasser and Frehner (1996). This, however, is related to different developmental stages of a forest. Moreover, it is impossible to keep a forest in a certain ‘desired’ condition over a long period of time because a forest is a dynamic system (Brang, 2001). Therefore, the local forest authority aimed for a mosaic of stand patches at different developmental stages. In order to achieve such a mosaic, the homogeneous optimal and optimal/ageing stands in particular had to be split up into smaller patches. By means of irregular stripe felling these patches were created and regeneration phases were initiated (Fig. 2.4). Once regeneration in an initially felled stripe has reached a secure stage, the mosaic-creation process will be continued by additional stripe felling using cable crane lines. This process has to be carried out during a whole developmental cycle of a stand, which takes about 200 years, in order to obtain phase-shifted mosaic structures (see Otto, 1994). In sparsely stocked ageing stands, cable crane
logging is inappropriate as excessively large gaps could come into existence. Therefore, in such stands only relatively few trees were felled in carefully selected positions in order to initiate regeneration. The cut stems were left on site and deposited diagonal to the slope direction in order to decelerate and to redirect rockfall. Stems that are deposited perpendicular to the slope direction result in large rock accumulations behind them and possibly in rock avalanches once the stems have decayed.

The local forest authority observed that in the course of felling activities the vulnerability to bark beetle infestation increased. During warm and dry summers this indeed resulted in two subsequent bark beetle invasions (see Fig. 2.4), but fortunately it was observed that bark beetle impact contributed to the mosaic creation process. When comparing the situation of 1988 and 2002 it can be seen that 15% of the optimal phase changed into a regeneration phase. Furthermore, 32% of the unstocked forest land and areas covered with shrubs also showed regeneration (Table 2.1).

Table 2.1. The partition of the different phases in the Außerbacher forest in 1988 and 2002

<table>
<thead>
<tr>
<th>Phase</th>
<th>1988 [m²]</th>
<th>1988 [%]</th>
<th>2002 [m²]</th>
<th>2002 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal and optimal/ageing phase</td>
<td>85506</td>
<td>26</td>
<td>69865</td>
<td>21</td>
</tr>
<tr>
<td>Late ageing phase (- multilayered)</td>
<td>101787</td>
<td>31</td>
<td>92336</td>
<td>28</td>
</tr>
<tr>
<td>Multilayered selection forest</td>
<td>92630</td>
<td>28</td>
<td>92630</td>
<td>28</td>
</tr>
<tr>
<td>Regeneration</td>
<td>2853</td>
<td>1</td>
<td>40626</td>
<td>12</td>
</tr>
<tr>
<td>Shrub vegetation, unstocked forest land</td>
<td>49284</td>
<td>15</td>
<td>36603</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>332060</td>
<td>100</td>
<td>332060</td>
<td>100</td>
</tr>
</tbody>
</table>

2.7 A silvicultural/socio-economic example

The forest of Sainte-Foy Tarentaise (France), which covers 1130 hectares, is located in the upper valley of the Isère river on steep glacially eroded valley slopes, half of the forest covers slopes with gradients higher than 30°. The forest occupies an intermediary position between a glacier (Mont Pourri, 3780 m a.s.l.) and a valley with intense traffic. The valley road leads to the ski resorts of Tignes and Val d’Isère and traffic was estimated at 13,000 cars daily in February 1993. Especially the forest in the “Raie” area, which covers 100 hectares with mainly quasi-pure spruce stands, provides protection of roads against rockfall. This forest is located on the steepest side of a southwest oriented slope.

In April 1986, rockfall caused the death of four people, confirming the magnitude of the problem and the need for treatment. The proximity of the Olympic Games in Albertville stimulated local authorities to initiate a rehabilitation project. The effects of the Viviane
windstorm in 1990, which destroyed several hectares of unstable stands, stressed the need for such a project. The first step in the rehabilitation project was a rockfall assessment using a rockfall trajectory simulation program (Cattiau et al., 1995). Forestry data were derived from a study carried out by Cemagref (Renaud et al., 1994). On the basis of these data, five forest structure types were derived, which were representative for the amount of rockfall energy that could be absorbed by the different forest stands (Cattiau et al., 1995). The model results showed that 60% to 95% of all rocks starting from the top would get to the road if the forest stands of that time were absent. The presence of trees, even scarce, reduced the rockfall hazard, either by stopping the rocks before the road or by limiting the height of the rebound, thus increasing the level of protection and reducing the cost of other measures, such as civil engineering. With the forest cover present at the time of investigation, 10% to 15% of all the simulated falling rocks would reach the road. Subsequently, several forest cover scenarios were tested and showed that a high level of protection was provided by dense forest stands with a high basal area (>25 m² per hectare), especially if these stands were located near the top of the slope. Less dense stands, but well located in mosaics, were also providing sufficient protection, even though the average stopping distance of falling rocks was longer. In case of an absence of forest cover at the top in combination with dense forest stands at the bottom of the hillslope, most of the rocks reached the road. On the basis of these observations two silvicultural options were discussed:

- establishing relatively homogeneous and dense stands with thick tree stems (DBH of 30 to 40 cm), or
- creating a structural mosaic, constituted of a regular alternation between ageing structures with initial regeneration and more dense ones with optimal growth.

The first option is very efficient, but unstable and needs intensive care to be maintained. The latter option, although less efficient in terms of road protection, appears nonetheless better adapted and less risky in the scope of extensive management, as the structural stability is better and the continuity of functions better guaranteed. Taking into account the local context and exploitation problems, the second option was chosen. The objective was to create structural patches of limited sizes (maximal 4 to 5 ares). The wood was removed by helicopter in order to avoid closing the road and dragging wood on the ground, which might destabilise rocks. The total costs were 21000 Euro, the wood was sold for 16400 Euro and therefore the operating loss was 4600 Euro. The Department of Savoie, fully aware of the importance of this operation for safety, granted the owner of the forest (i.e. the local town) 15000 Euro. Therefore, net profit for the owner amounted to 10400 Euro. At present, the forest provides
sufficient protection against rockfall, but active management is required to maintain this level of protection. Without the subsidy given by the Department of Savoie, the described operation would have been cancelled. This indicates that a constant dialog between the people working in and managing the mountain forests and forest researchers is important. In addition, efforts to convince local governments of the importance of adequate management of protection forests are also needed.

2.8 Synthesis: interaction between human and natural systems

Forest ecosystem integrity is rooted both in ecological as well as in social and economical aspects, as forest ecosystems are to provide functions of values to humans, which requires ecological stability. A forest is a dynamic system, continually changing in response to natural and human disturbances. Some disturbances help to maintain forest ecosystem integrity, while others threaten it. As shown by the example in the Austrian Alps, forest management interventions were required to restore the integrity of protection forests. The loss of integrity was due to the long history of direct and indirect human impact on the forest ecosystem in combination with the natural disturbances as well as the natural biotic processes. This resulted in a situation where silvicultural measures were required. This is an excellent example of a panarchy. A panarchy is a structure in which systems, including those of nature and of humans, as well as combined human-natural systems, are interlinked in continual adaptive cycles of growth, accumulation, restructuring, and renewal (Holling, 2000; Gunderson and Holling, 2002). Panarchy has evolved from hierarchy theory, firstly applied in geoecosystem research by Allen and Starr (1982) and O’Neill et al. (1986). They initiated an increase of theoretical understanding by viewing the landscape as a multi-scale dynamic system in which biotic and abiotic processes interact. However, both the adaptive nature of such systems, organized by periodic and transient phases of growth, conservation, collapse and reorganization and the interaction with human systems has tended to be lost. Therefore, panarchy, a term devised to describe evolving hierarchical systems with multiple interrelated elements, offers an important new framework for understanding and resolving this dilemma. The steering variables in the panarchy of forest that protects against rockfall are the frequency and magnitude of rockfall, growth of individual trees, regeneration and breakdown of the forest as well as silvicultural interventions. These variables are all interacting. At the same time, some of them are the result of an adaptive cycle within themselves. For example, whether or not silvicultural interventions will be carried out in protection forests depends on
factors acting in social, economical and to a lesser extent forest ecological systems as shown by the example in the French Alps.

There is a need for the theoretical framework panarchy provides. The examples show that forest authorities are aware of techniques to improve the stability of protection forest ecosystems, but the problem is that current forest management is often still a kind of trial and error, because the exact consequences of interventions for forest ecosystem dynamics are not known. This accounts both for the impact of the natural hazard the forest should protect against as well as the future dynamics of the forests ecosystem. Despite this knowledge gap, which is due to the lack of research and the fact that previous disturbances affect the development of a forest for a long time, foresters are increasingly aware of the self-organising capacity of forests, which is indicated by the fact that they do take into account natural forest ecosystem processes as far as possible in the silvicultural measures taken. It is known that it is particularly important not to work against the stand development but to exploit forest dynamics for silvicultural objectives. Especially this should be investigated more, as recognized by many authors (Attiwill, 1994; Andersson et al., 2000; Bengtsson et al., 2000; Führer, 2000; Kräuchi et al., 2000; Bebi et al., 2001; Brang, 2001; Schönenberger, 2001a).

Regarding the interaction between forests and natural hazards, research should shift focus to mountain geoecosystem functioning. In replication of Troll (1971), Rowe and Barnes (1994) and Huggett (1995) the term geoecosystem is used to place the emphasis not only on the biosphere, but also on the atmosphere, hydrosphere, lithosphere and pedosphere, which are dynamic and important parts of mountain forest landscapes. Understanding geoecosystem functioning differs from assessing how geoecosystem functions are performed; it is about understanding how our surrounding dynamic ecosystems, which are affected by our social and economical systems, operate. Therefore, panarchy is a promising way forward to improve ecosystem management of protection forests in mountains and to sustain ecosystem integrity in general. Because if the panarchy of a protection forest would be understood better, different silvicultural interventions could be simulated to test its effect on the integrity of the forest ecosystem. Consequently optimal silvicultural procedures could be pinpointed.

This chapter presented two real world examples regarding the management of forests that protect against rockfall. In addition, the theoretical nature of the state-of-the-art concepts of ecosystem management has been described. Overall, this chapter indicates a gap between the theory and practice of protection forest management. To help decrease this gap, the following chapters of this thesis focus at the development of a method for obtaining more knowledge about the interaction between abiotic (rockfall) and biotic (protection forest
structure) factors in a mountain geoecosystem. This method and the obtained knowledge will be another step towards understanding the panarchy of protection forests in mountain geoecosystems.