3.6 Protection against Natural Hazards

Urs-Beat Brändli, Anne Herold

Sustainability and Forest Functions

The goal of the Swiss National Forest Inventory is primarily to monitor the large-scale forest development with respect to the sustainability of the forest (BRÄNDLI 1993). The international consensus regarding the sustainable forest management, together with suitable criteria and indicators, served as a reference for the NFI. “Sustainable management means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems” (Resolution H1 of the Ministerial Conference on the Protection of Forests in Europe in Helsinki 1993).

In Article 1, the federal forest law names three groups of forest functions: the protective, the (social) benefit, and the production function. The nature and landscape protective functions are considered as (social) benefits. According to today’s understanding, the forest functions are divided into the demands of the society (demand) and the effects of the forest (supply). “Forest functions encompass those tasks that are accomplished by the habitat forest (effects or potential of the forest) and those functions which should be accomplished (demands by human)” (BERNASCONI 1995; BUWAL 1996a). The differences recognized between the demands and the effects require both political and practical action.

Since in the second NFI neither the social demands nor the effects of the forest could be directly assessed, the forest functions were derived later through models. In the present chapter those models regarding the protective functions are discussed. The derived attributes and measures for the production function (timber production) are presented in Chapter 3.2 “Estimation of Standing Timber, Growth and Cut”. The models for recreational and nature protective functions are discussed in Chapters 3.7 and 3.8.

Term “Protective Function”

In this chapter, the protective function of the forest always refers to the protection of humans and includes, according to WULLSCHLEGER (1982), the protection against *natural hazards* (rockfall, soil erosion, landslides, scree, torrents, and avalanches) and the protection against *civilization hazards* (noise, exhaust fumes, soot, water pollution, and dust). In a mountainous and densely populated country such as Switzerland, the protection against natural hazards is of the utmost importance, which is why in the second NFI this function was primarily assessed.

According to the current forest law of Switzerland, any forest could theoretically be treated as a protection forest. The term “ non-protection forest” no longer exists. Despite this, a forest is usually called a protection forest only if humans or tangible property is protected directly or indirectly against avalanches, rockfall, landslides, erosion, mud flow, or floods. The new forestry law from 1991 coined the term “forest with special protective function” (BSF forest) as an instrument for the incentive policy. BSF forests are forests that protect **humans or substantial tangible properties** against **direct natural hazards**. This interpretation was pertinent to the models in the second NFI.

Models of the Second NFI

The term “protective function” encompasses the social demand for protection (hazard potential, damage potential) and the effects of the forest against natural incidents (protective effect). In general practice and within the NFI specifically, the hazard potentials and the objects at risk are determined first in order to designate protection forests. Wherever these overlap there is potential for damage. The forest stands in the catchment area to such processes are declared protection forests. Whether this type of forest is structured as such that it provides the optimal protection is determined in the NFI later with the help of simple models with nominal values.

In the second NFI, models were used instead of field expertise to designate protection forests to get nationwide comparable results. Models exist for **avalanches** and for **rockfall**. The natural hazards landslide, erosion, mudflow, and floods are not considered here since no suitable models are available yet. The present models for the protection forest against avalanches and rockfall are relatively rough and should be further developed and refined, or be replaced with more suitable models.

The models employed in the second NFI to determine the hazard and damage potentials and the effects of the forest are explained in the following. Apart from the protective effect against rockfall, the models are based on research or on models from other projects. Most of the models were developed in connection with the forest survey program (WEP) 1992–1995 (BLEISTEIN and JOST 1993) within the modules "natural hazards" and "minimum silvicultural operation" for the local assessments in the field. The quality, significance, and applicability of these models for the sampling survey of the NFI were intensely studied between 1996 and 1997, and were discussed with experts. The results of these verifications are stated with explanations for these models.

3.6.1 Protection Demands of the Society

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Society must first demand protection forests before they can be designated as such. Protection demands and the term "special protection forests" are defined as functions of the potential natural hazards and the damage potentials:

Protection demands = f(hazard potential, damage potential).

The appropriate mapping of the hazards is part of the cantonal projects, which after the end of the second NFI has been only partially completed. Due to the different cantonal survey methods, they are not suitable as a basis for a nationwide interpretation. This is one reason the second NFI had to work with models. In the NFI it was not necessary to quantify exactly the protection forest area. The so-called NFI2 protection forest is more a tool for the stratification of the total forest for a differentiated qualitative analysis of the state of the forest, and for analyses of the forest effects in space and time. For the characterization of the NFI2 protection forests and forests with special protective functions, see also BRÄNDLI and HEROLD (1999).

3.6.1.1 NFI Model to Determine the Protective Demands

A cost-effective determination of the hazard and damage potentials in the NFI grid and for all of Switzerland had to be based on already existing material. Since several necessary pieces of information were not available on a national level, or with only low resolution, only very rough models and general statements were possible.

The development of the models and the determination of the protective functions was conducted on the basis of existing data, such as the digital elevation model or the so-called pixel maps. Furthermore, a simplified model was assumed for avalanches and rockfall (fall analysis with the generalized gradient method) which was calculated with the geographic information system Arc/Info. The Geo7 Company, located in Bern, Switzerland was entrusted to develop the model (MANI and BALMER 1996). This work was based partially on the findings of the work for the module "supporting measures natural hazards" (BUWAL 1996b). The model's assumptions for the NFI2 protection forests were in accordance with those by BUWAL (1993).

The generalized gradient method (see below) does not allow the evaluation of incidents caused by torrents (floods, erosion, and mudflow). It only encompasses the designation of hazards due to rockfalls, avalanches, and landslides. At the time the second NFI was conducted no practical efficient model existed for the evaluation of incidents caused by torrents. The landslides that were modeled did not agree well with the terrestrial NFI assessment (traces of landslides), so these model results could not be used any further. In addition, too little is known about the ideal forest structure in preventing landslides or erosion (i.e., the requirements for optimal forest effects).

In all of these cases it is not possible with the present knowledge to qualitatively evaluate the protective effects. The protection forests designated in the second NFI were limited, therefore, to those with potential protective effects against avalanches and rockfall.

3.6.1.2 Data Foundation[1]

Elevation Model

The most important basis for the designation of protection forests in the second NFI was the **digital elevation model DHM100** of the Federal Office of Topography (see Chapter 2.7). The model was built with manual map interpretations (RIMINI grid relief) and was interpolated onto a 100 meter grid. The high resolution DHM25 was not yet available for all of Switzerland and had some critical drawbacks for the hazard simulation. Since the spot height of the national map was not used for the interpolation, the ridge height (of mountain ranges) in rocky areas (with contour lines every 100 meters), and consequently the slope, were sometimes significantly underestimated. The additional work necessary would have been too costly to eliminate this. For the DHM100, a few preparatory steps were sufficient, such as the elimination of unrealistic depressions (sink holes) in the DHM.

The representation of the topography in a 100 meter grid led inevitably to a smoothing effect of the relief, which was especially noticeable in the calculation of the slope. A comparison of the DHM100 with the DHM10, which had a 10 meter grid width, in the Mattertal valley (canton Wallis) conducted by the Geo7 Company showed that slopes under 30° were overestimated and slopes over 30° were underestimated. These empirical values were taken into consideration when the thresholds (critical slopes) for the designation of the hazard areas (see below) were determined.

Examples of critical slopes

uncorrected	corrected
11°	18°
22°	25°
28°	28°
34°	30°
50°	37°

The Mattertal, however, was not representative of the topography for all Swiss regions, as was shown by our analyses from the NFI data. By comparing the terrestrial measured slopes of the NFI sample plots (similar to the slopes from the DHM10) with the hectare slopes (identical to the DHM100), strong regional differences can be seen (Figure 1). The regions Alps and Southern Alps had, as expected, the highest similarities with the curve of the Mattertal (only 14 NFI sample plots). Regions with relatively short slopes, frequent inclination changes, and relatively smooth topography were poorly represented by the Mattertal, in particular the Swiss Plateau.

Due to time and cost considerations, optimization specifically for each region could not be conducted. As a consequence, in certain regions the correction function used in the NFI models overestimated the critical slope for the DHM100 and systematically underestimated the potential of rockfall and avalanches. This was especially true in the Jura and the Plateau, where only rockfall occurs, and to a lesser extent in the Pre-Alps and on the north side of the Alps (northern Alps region).

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[1] The foundation for the data, the simulated hazard area, and the Arc/Info macros are only available at the WSL for the employment and updating of the damage potentials for the NFI. Other applications have to be arranged with the GEO7 Company, Swiss Federal Statistical Office, and the Federal Office of Topography.

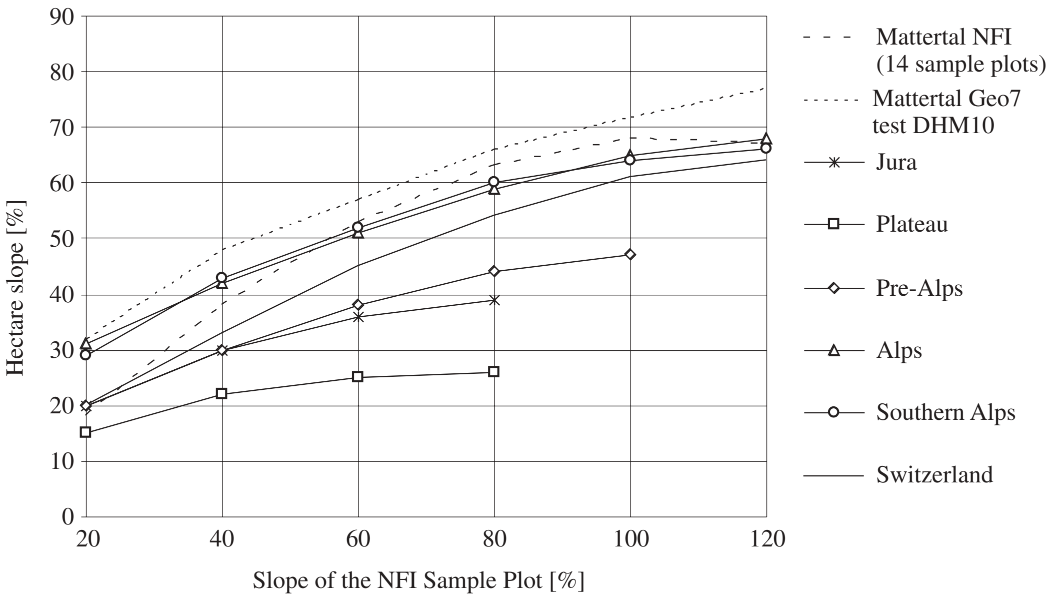


Figure 1. Relationship between hectare slope and sample plot slope.

The slope correction was, in general, relatively imprecise for flat or steep slopes, as for example, the upper limit at which avalanches can emerge (50°). The uncorrected slope of the sample plot from the terrestrial survey was, therefore, used as the breaking criterion for avalanches (see below).

Damage Potential

The threat to human lives and/or substantial tangible property (i.e., roads and **settlement areas)** was assumed to be the damage potential. The latter was taken from the **Area Statistics** 1979/85 (BFS 1992) which, with a grid width of 100 meters, corresponds with the resolution of the DHM100. The damage potential “settlements” in the NFI included industrial and building areas, as well as utility structures and waste facilities (power, waste water, etc.). Whether these buildings were inhabited all year, occasionally, or not at all, could not be detected with the material at hand.

The transportation routes were taken from the **vectorized national map 1:200,000** (Vector 200, as of 1981/85) from the Federal Office of Topography. For the assessment of the damage potential, the vector data set “Roads.dgn” (expressway, main roads) and “Rail.dgn” (railroads) were used and included the station buildings from main, side, and mountain railroads, but did not take into account tunnels, smaller roads, and lanes/footpaths. These vector data were combined with the 100 meter grid. For the final “sampling in the GRID,” the edited **NFI sample plot data in the 500 meter grid** (forest/non-forest) was used.

The digitized Swiss road network was not categorized with respect to the damage potential. Thus, only the most important first and second class roads (indicated in red and yellow on the map) could be considered in the highly simplified model. With this model, all transit roads were taken into account; however, some important local access roads in the mountains were not included. The reported damage potential “roads” was, therefore, underestimated in the second NFI.

3.6.1.3 Designation of the Protection Forest

Natural hazards are natural incidents that could endanger human lives and tangible property. The designation of areas affected by such natural incidents was conducted with the help of the generalized gradient method. The slope, flow direction, and flow height was calculated for each pixel cell as well as the generalized gradient for each pixel cell that had damage potential (settlements, important transportation routes) (Mani and Balmer 1996). With these data the starting zones and trajectory areas for rockfall and the starting zone of avalanches can be designated. The ratio of total flow length and flow height equals the generalized gradient (see Figure 2). All damage potentials with a generalized gradient over a certain fixed threshold (see below) are in the range of the respective process. The designation of the NFI2-protection forest is explained in Figure 3, using the NFI2-avalanche protection forest in the Southern Alps as an example.

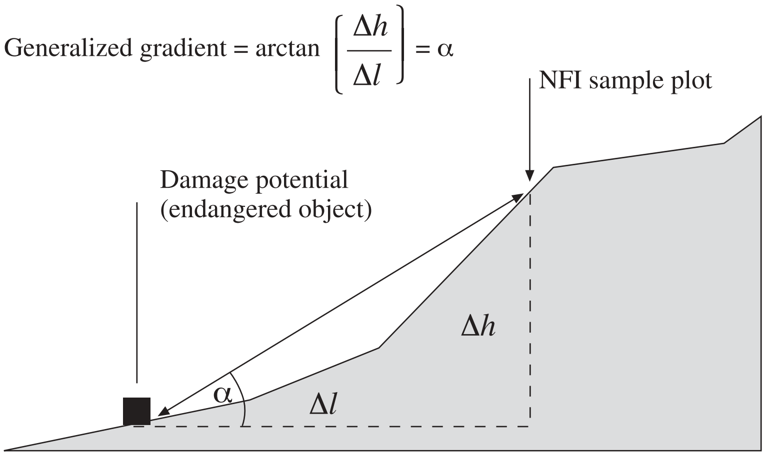
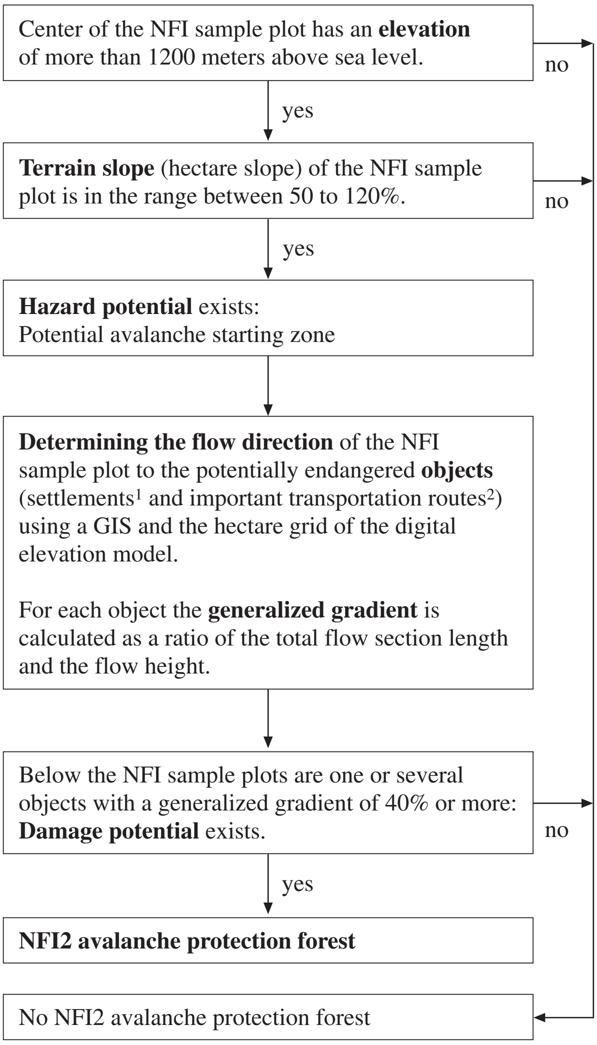


Figure 2. Concept of the generalized gradient method. Δl: Sum of all flow section lengths. Δh: sum of all heights (Mani and Balmer 1996).

Only those hazard areas which were directly related to a damage potential were designated. Settlements and transportation routes were distinguished. Connecting these hazard areas with the forested NFI sample plot points of the 500-meter-grid resulted in the **NFI2-protection forest**.



[1] Settlement areas according to the area statistic 1979/85.

[2] Transportation routes from the data set VEKTOR200 (L+T), as of 1981/85.

Figure 3. Classification schematic for the designation of NFI2 avalanche protection forest using the example of the Southern Alps.

Rockfall

In the rockfall model, all areas with a slope of 34° (65%) or more, and a generalized gradient to the next damage potential of at least 34°, were designated as starting and/or transit areas for the rockfall. Other relevant quantities (tectonic, geology, ledges of rock, etc.) were not considered. The threshold, with respect to the slope and generalized gradient, were taken from the papers of the forestry working group against natural hazards (RICKLI *et al.* 1994). These thresholds were more restrictive than those of the Swiss Forest Agency with 27° and 22° respectively (BUWAL 1993) that were also intended for boulders of extreme size that could barely be stopped or slowed down by the forest.

Avalanches

The positive effect of a well-developed avalanche protection forest is founded in the ability to reduce the risk of triggering an avalanche. Avalanche protection forests are, therefore, located in the potential starting zone of avalanches. That is to say, they are located on steep slopes with deep snow. As a consequence, only potential avalanche starting zones with a sample plot slope between 28°–50°, or 50–120%, were identified. Slopes over 50° were considered to be too steep for avalanches, since it is not possible under these conditions for enough snow to accumulate.

Lower elevation limits for avalanches were set at 900 meters above sea level for the Northern Alps, 1100 meters above sea level for the inner Alps, and 1200 meters above sea level for the Southern Alps. The minimum generalized gradient was in accordance to the recommendation in the BUWAL (1993) set to 22° (40%).

Landslides
Areas with a slope (depending on the geological substratum) in range of 16–37° (29–120%) or 23–37° (43–120%) were designated as landslide areas. The Geo7 Company in Bern, Switzerland evaluated the rock classes from the "Simplified Geotechnical Map of Switzerland" (BFS 1995) with respect to their susceptibility against landslide processes. The position accuracy of the digital geotechnical map is, on average, 200 meters. The damage potentials that have a generalized gradient over 11° (20%) and have a distance of less than 500 meters to the area of origin were in the range of the landslide process.

3.6.1.4 Verification and Comparability

The models employed in the second NFI indicated, as a result, that the proportion of avalanche and rockfall protection forests is 9% of the total Swiss forest. This proportion varies between 8% and 20% in the Alps, depending on the regions (BRÄNDLI and HEROLD 1999). The survey teams in the field observed signs of snow movement on 59% of the sample plots in the NFI2-avalanche protection forest. Signs of rockfall were noted on 53% of the plots in the NFI2-rockfall protection forest, and on 19% of the plots in the remaining forests. The modeled potential landslides did not seem to be correlated with the signs of landslides observed in the field. For this reason the model "landslides" was not used further in the second NFI.

Compared to the designation conducted by the cantons, the results from the NFI indicated far less protection forest by canton. The area of the NFI protection forest amounts to 58% to 68% (rockfall) and 25% to 52% (avalanches) of the corresponding BSF forest areas of Grisons and Bern.

One reason for these results is because of the more restrictive NFI model assumptions for the natural hazards, as compared to those models of the canton Grisons, especially with respect to triggering avalanches. Furthermore, the second NFI identified less damage potential, since the methods used only the most important roads of class 1 and 2 (ignoring some of the local access roads in the mountains) and ignored scattered settlements in the Area Statistics. Finally, the cantonal BSF forest designation, with more of an area/spatial character (treatment units), resulted in a larger area than did the sampling inventory that had point decisions. For these reasons, and since landslides, torrents, erosions, and mudflows were ignored, the NFI protection forest proportions of 8% to 20% in Alpine regions are overall much lower than the BSF forest proportions in the mountainous cantons, amounting to approximately 30% to 40%.

Based on the maps with a scale of 1:25,000, 1:50,000, and 1:100,000, a rough, ocular plausibility check of the NFI2-protection forest was conducted in four areas of the cantons Valais, Ticino, Grisons, and Bern. According to these regional assessments, approximately 63% to 72% of all NFI2-protection forests fulfill the conditions of forests with special protective functions. In the canton Grisons 18% of the NFI2-rockfall and 9% of the NFI2-avalanche protection forests are definitely not special protection forests, since the supposed endangered objects are not really located in the hazard areas. This means that in most of these cases the objects were located at the counterslope or the process could not reach the objects because of extreme energy losses due to abrupt changes in slope and/or direction of trajectory. Such cases are not recognized with the generalized gradient method.

Comparisons with mappings of the cantons of Bern[2] and Grisons indicated that on average 56% to 59% of the NFI2-rockfall protection forests and 59% to 78% of the avalanche protection

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[2] The mapping in Bern canton is based on a newly developed, refined model of the Geo7 Company, Bern, Switzerland. The employment of this extensive procedure was not possible at a national level during the time of the second NFI.

forests were located within the perimeter of the corresponding “forest with special protective function” (BSF forest) of these cantons (Table 1). Some of the NFI2-protection forests were shrub forests or open stands which were not mapped as forests by the cantons. Most of the differences, however, were based on the inaccuracies in the second NFI models. These differences included the rough terrain model, the inaccuracies with respect to position and relevance of the endangered objects, and most importantly, the shortcomings of the generalized gradient method. Since the latter did not account for the change of the avalanche trajectory, slope of the mountain and counterslopes, some unlikely events were simulated with relative frequency in the side valleys of certain regions – especially in the Leventina area (Ticino).

Despite these shortcomings, this model is, at the moment, the only practical method to select the NFI forest sample plots with protective functions until the extensive surveys of the cantons or other groundwork is available that will cover Switzerland entirely on a national level.

Table 1. Characteristics of the NFI2 protection forest and of the BSF forests.

	Protection Forest according to NFI2 (NFI2 protection forest)	BSF forest according to the forest law (BSF: special protection function)
Goal and context	– Long-term monitoring of state and development for the protection forests at a national level, differentiated by type of natural hazard. – Instrument for science with reproducible results.	– Determining the protection forest area for regional planning and silvicultural measures at the cantonal and local level. – Instrument for the designation of functions. – Incentive policy instrument.
Hazard potential	– Avalanche and rockfall. – Mathematical measure based on an simplified model.	– Avalanche, rockfall, landslide, erosion, torrent, and mud flow. – Mathematical and empirical measures.
Damage potential	– Occupied and unoccupied buildings. – Most important transport systems (railways and roads).	– Permanently occupied settlements. – All important transportation systems and feeder roads for permanently occupied buildings.
State of the survey	– Complete for Switzerland. – Temporary solution.	– Was not finished in 1996 for all cantons.
Procedure	– Point decision for the NFI sample plots.	– Area decision for larger forest parcels (planning unit, perimeter)
Comparability	– Can be compared at a national level. – Separate evaluation of avalanche and rockfall protection forest possible. – From the NFI protection forest 56-59% (rockfall) and 59-78% (avalanche) are also BSF forest in the canton BE and GR.	– Difficult to compare at a national level. – Differentiation of the BSF area by the individual natural hazards is not planned or carried out in every canton. – The comparability of the methods and the plausibility of the results was not systematically studied at a national level.

3.6.2 Current Protective Effect of the Forest

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The protective effects correspond to the current capability or suitability of the stand to prevent certain hazardous natural incidents before they occur, or in order to dampen their effects. The actual protection, that is whether or not natural incidents actually reach an object, is always the result of the interaction between site factors, stand properties, and incident properties. Nonetheless, the protective effects of the **forest stand** are analyzed in the second NFI independently of the other protective effect factors. This approach is very reasonable, since in the second NFI no detailed information exists about the site conditions along the path the incidents fell or about the incident properties (mass, energy, etc.). Thus, in the second NFI only the quality of the protection achieved from the stands was investigated, and not whether the endangered objects were protected in the end.

In the models of second NFI for the current protection effects of the forests against avalanches and rockfall, the site-specific potentials were not accounted for. For example, it was not considered (in the models) that portions of a rocky area could not be fully forested, or that certain sites are only appropriate for larch trees which are leafless in the winter and thus are hardly suitable as protection against avalanches. The models show only how well the current stocking protects. In contrast, the analysis of the structural sustainability in the protection forest (Chapter 3.6.3) includes the site properties through the model of the potential natural forest community (PNV) (Brzeziecki *et al.* 1995).

3.6.2.1 Current Protective Effects against Avalanches

Anne Herold

Background

Forest stands may rarely or not at all slow down avalanches if their fracture lines are above the stands. It is, however, possible that the forest can reduce the risk of triggering **forest avalanches** by intercepting snow in the tree crowns thus interrupting the evenness of the snow cover as well as minimizing snow accumulation due to the wind. This is why the break off of forest avalanches indicate weakened or absent protective effects of the stocking. The evaluation of the protection forest against avalanches is, therefore, based in the second NFI on the research of forest avalanches conducted by Meyer-Grass and Schneebeli (1992).

This research investigated how the type of stands, the site and the type of snow conditions in the Swiss Alps affect the start of forest avalanches. The goal was to determine which attributes and quantities had the highest influence on forest avalanche events. Table 2 (taken from Meyer-Grass and Schneebeli 1992) presents a synthesis of the relevant parameters that trigger forest avalanches along with their critical values (thresholds). These thresholds depend on five types of forest stands which are presented.

Table 2. Parameters and thresholds important for the start of forest avalanches according to Meyer-Grass and Schneebli.

	Forest type				
Parameter	Broadleaf	Broadleaf /conifer	Conifer evergreen	Conifer evergreen/ not evergreen	Conifer not evergreen
Crown coverage (%)	<80%	<70%	<35%	<30%	<35%
Width of gaps (m)	>5 m	>5 m	>10 m	>10 m	>10 m
Coverage of ground vegetation (%)	>50%	>50%			
Slope (°)	>38°	>42°	>38°	>35°	>32°
Number Stem/ha (DBH>16cm) depending on the slope:					
30°	50		50	200	300
35°	250		150	300	300
40°	600		250	400	300
45°	850		350	550	300
50°	1100		450		300

Plausibility in the field

Meyer-Grass and Schneebeli (1992) specify the number of stems per hectare trees with a DBH above 16 cm (No./ha >16) as the relevant stand density. Not considered here is the fact that with increasing diameter the tree crown gets wider and can therefore achieve the same snow interception effects with fewer number of stems. In addition, initial model calculations using NFI data suggested that this measure of stand density is not optimal for older stands (with larger diameters and fewer numbers of stems).

Using the sum of all diameters at breast height per hectare (∑DBH) as a measure of density includes the stages of development. In the summer of 1996 both stand density measures were for this reason studied with respect to the plausibility by comparing the nominal and the actual value (threshold/stand value) of selected stands in Domleschg (GR) between 1100 and 1700 meters above sea level. For this comparison, stands for all three needle winter forest types (evergreen, leafless in the winter, and mixed) were selected.

Before the data were gathered each stand was first ocularly assessed as to whether the snow interception from the current crown closure was sufficient, not sufficient, or was unclear to prevent the start of avalanches. The goal was merely to test the plausibility of the results for both density measures in obvious situations thus avoiding fundamental misinterpretations. In addition, the crown closure was estimated. It was noted whether a gap of more than 10 meters in diameter between the stand border existed. Subsequently, the diameter of trees on “fictitious” NFI sample plots were measured and both density measures were calculated. The results of both nominal/actual value comparisons were then compared with the ocular evaluation. This study was also conducted in the surrounding stands on some “real” NFI sample plots.

The results confirmed the assumptions that for old timber, the DBH sum is the more suitable density measure. In stands with somewhat smaller diameters (young and medium timber), both density measures are either equally good or the DBH sum is more plausible than the number of stems (No./ha >16). As an example of these interpretations, a stand with older timber (d_{dom} ≥60 cm), 100% spruce and 90% crown closure without gaps can be used. It is obvious that such a dense stand can prevent, even in steep terrain, the start of an avalanche. The DBH sum (165 m/ha) exceeds the threshold even for the steepest slopes, while the number of stems (320 No./ha) does not reach the threshold for a terrain slope that is over 90%.

Derivation of the Avalanche Protective Effect in the Second NFI

For each sample plot point, the threshold of the appropriate forest type (nominal) is compared with the observed or measured value of the sample plot (actual). The more thresholds that are being reached, the higher the probability is for good protective effects. The NFI attributes used for the nominal/actual value comparison were:

- **Winter forest type**: Broadleaf forest, broadleaf/coniferous forest, evergreen coniferous forest, mixed, evergreen/leafless in the winter coniferous forest, winter leafless coniferous forest. Calculated with the help of the mixture proportion and the basal area proportion of larch.
- **Slope**: Slope of the interpretation area. Calculated using the elevation measurements of the grid points in the aerial photograph.
- **DBH sum** (∑BHD): Sum of the tree diameters at breast height. Calculated with the help of terrestrial assessed trees on the sample plots and extrapolated to a hectare.

As discussed above, the ocular plausibility in the field indicates that the results of the nominal/actual comparison of the DBH sums in the medium and old timber are more plausible than those from the stem number method. The crown closure determined from aerial photographs is also slightly higher correlated with the DBH sum than with the number of stems of those trees with a DBH above 16 cm. The values of the DBH sum, which correspond to the nominal number of trees by Meyer-Grass and Schneebeli, were determined from the NFI data with a binomial regression, where the stem number of trees over 16 cm DBH is the independent variable and the DBH sum is the dependent variable. Table 3 shows, as an example, a high thinned spruce stand on a medium site (site class 16) when during the stand development, the values for the stand density parameter (as determined from the yield table, EAFV 1968) reach the thresholds. If the nominal values for the evergreen forest and 90% slope are substituted into the model, this optimally stocked “yield table stand” (even-aged, single-species stand, high thinned, and even crown closure) would reach the stem number between the age of 50 and 110 years; whereas the stand surpasses the threshold of the DBH sum starting at an age of 40 years during the full time of development. The latter result appears to be more plausible, especially for older, fully stocked yield table stands, since the snow interception is also sufficient in older stands when they are fully stocked.

- **Gap**: Presence of stand gaps on the interpretation area. Gaps with a dimension of at least 10 meters from stand border to stand border were recorded, as long as they were at least partially in the interpretation area.
- **Coverage**: Crown coverage. Calculated from the interpretation of 25 grid dots in the aerial photograph.

The derivation of the protective effects with the help of these five parameters is illustrated in Figure 4. Thresholds are shown in Table 4.

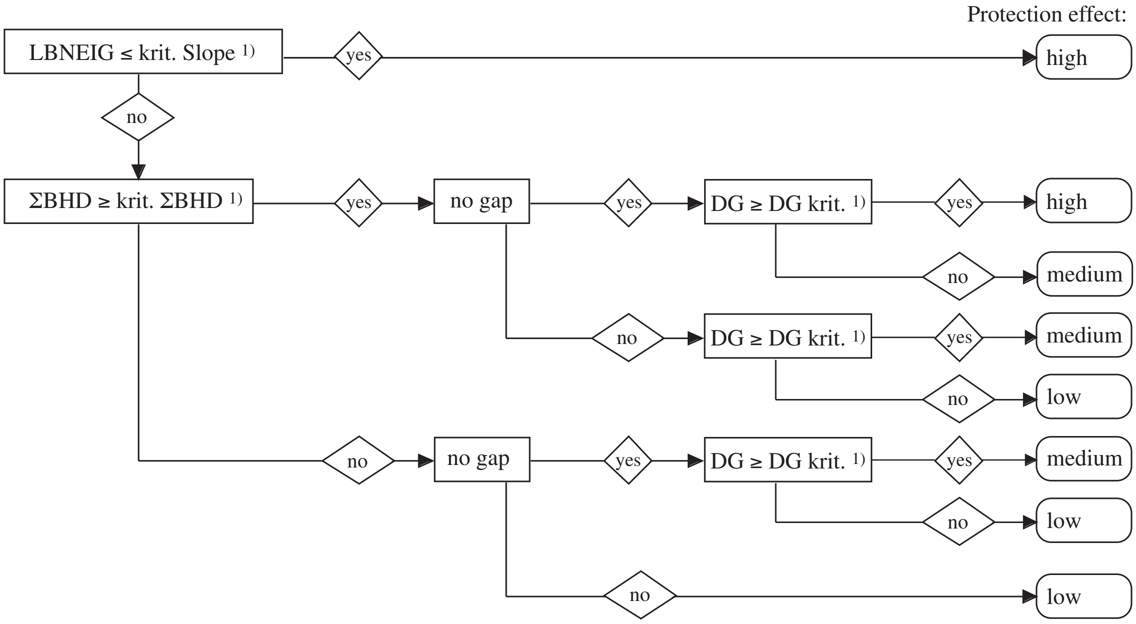

Figure 4. Derivation of the protective effect against avalanches.
∑DBH/ha: Sum of all diameters at breast height per hectare.
krit.: Critical value (threshold) according to Meyer-Grass and Schneebeli.
LBNEIG: Slope of the interpretation area, which is determined from aerial photographs.
DG: Crown coverage of the stand.
^{1} from Table 4.

Table 3. Comparing the stand density parameter DBH sum (∑DBH/ha) and number of stems (number stems >16/ha).

Stand age (year)	Stem number >16/ha (DBH >16cm)	∑DBH/ha (DBH >12cm)			
20				Example:	
30	**0**	**24.8**		Nominal values	
40	**237**	121.2		for evergreen forest and	
50	510	156.7		90% slope:	
60	596	167.2		Stem number>16/ha (DBH >16):	300
70	594	164.0		∑DBH/ha (DBH >12):	97
80	525	149.1			
90	451	135.6			
100	394	125.7	Threshold fulfilled		
110	340	116.5	**Threshold not fulfilled**		
120	**290**	106.6			

Values determined from the yield table “spruce, site class 16” for the “remaining stands”.

Table 4. Critical slope and crown coverage by winter forest type.

Slope and crown coverage in %	Winter forest type				
	Broadleaf	Broadleaf /conifer	evergreen	evergreen/ not evergreen	Not evergreen
Slope	70	70	70	64	58
Crown coverage	80	70	50	50	50

Critical stand density by slope and winter forest type in ∑DBH/ha	Winter forest type				
Slope of terrain (%)	Broadleaf	Broadleaf /conifer	evergreen	evergreen/ not evergreen	Not evergreen
59–64	▨	▨	▨	▨	100
65–70	▨	▨	▨	98	100
71–77	129	91	65	114	100
78–84	182	91	81	130	100
85–92	219	91	97	153	100
93–100	254	91	112	176	100
101–109	288	91	128	176	100
110–145	321	91	144	176	100

▨ The stocking density is not relevant in the marked area.

Discussion

The main drawback of the research on which the model is based (Meyer-Grass and Schneebeli 1992) is the short observation period of only five winters, of which none were typical avalanche winters. The variability of the snow and weather conditions is more accurately recorded the longer the observation period is. The avalanche frequency and the extent of avalanches depends directly on these conditions.

Forests with lower densities and lower crown closures can still protect against avalanches occurring in normal annual snow and weather conditions. However, higher thresholds, which means denser forests, are needed if the forests are intended to offer protection from rare, heavy, or even extreme conditions. That is why the standards with respect to the forests (meaning the thresholds at which the start of avalanches are prevented), should always be determined by considering the heaviest snow and weather conditions under which the forests are still expected to offer protection. These "relevant snow and weather conditions" are best characterized by the return period[3]. Over longer observation periods, the threshold values could be established differently for conditions that occur annually (normal), every 20 to 50 years (rare), and possibly every 100 years (extreme).

Meyer-Grass and Schneebeli (1992) wrote in relationship to this the following observation: "... in the observed area and during the observed years, no winter with high avalanche intensities occurred. The number of stems per hectare represent, therefore, rather lower threshold values; avalanche fracture lines could probably also occur in denser stands or stands with slopes that are not as steep." In other words: The selected model leads to conclusions that are only valid for "normal" snow and weather conditions with shorter return periods. As a next step it should be attempted to determine the number of years for these return periods. Meyer-Grass and Schneebeli (1992) regarded an extrapolation of the threshold values to longer return periods as theoretically possible if a series of observations of avalanche frequency and intensity exists which is undisturbed by factors unrelated to weather.

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[3] Also called recurrence interval or recurrence period. The long-term average interval of the time expressed in number of years within which an event will be equaled or exceeded.

3.6.2.2 Current Protective Effects against Rockfall

Urs-Beat Brändli

The effects of forests against rockfall are highest in the starting zone and runout zone. Most of the protection forests are located, however, in the transitional zone (track) where, according to BUWAL (1993), their effectiveness is very limited. If a falling (rockfall) process is already in progress, forests can rarely bring it to a complete stop. Forests provide, however, a very significant contribution by reducing the energy which lessens the bouncing of tumbling rocks and blocks. For the evaluation of forest effects, all NFI2-rockfall protection forests are considered transitional zones, due to the small number of sample plots as well as missing detailed research about forest effects in different zones.

Background

Effect Factors of the Forests against Rockfall

Today, the knowledge about how forests protect against rockfall is still not adequate and by far less extensively understood than for forest effects against avalanches. Qualitative relationships between influential factors are described, but knowledge regarding the effectiveness of a forest is missing (i.e., the maximum possible effects a forest can have with an optimal structure). Forests have a certain effect against rockfall as Jahn (1989) showed in an experiment. A site specific, absolute evaluation of the effects of a forest is, however, not possible on this basis.

If aspects such as terrain slope, terrain roughness, ground cover, or subsoil are not considered and only stocking is studied, the following effect factors are examples that can be found in literature.

Positive Effects	**Negative Effects**
Starting zone	
– Closed forest	– Gaps
Transitional (track), and runout zone	
– Closed forest	– Gaps
– Dense stocking	– Lamellar structure (forest aisle, free of trees in falling direction)
– Wide forests	
– Large "effective DBH" (Suda 1989) (comparable with Σ DBH in NFI)	– Tree distance in falling direction >30 m (Gsteiger 1989)
– Trees with a DBH larger than 10 cm (Suda 1989)	
– Large number of trees/hectare	
– Large DBH: high energy absorption	

Sustainable Effects (aspects of the stability standards)

- Stands with permanent regeneration and high DBH dispersion (plenter forest)
- Less sensitive tree species:
  - Larch is more resistant than spruce/fir
  - Sycamore maple and basswood are more resistant than beech

Extent of the Rockfall Phenomenon in the Forest

According to the second NFI (Brassel and Schwyzer 1999), approximately 16% of the NFI sample plots showed signs of rockfall; in the region of the Alps, this amounted to 27%. In all of Switzerland approximately 3%, and in the Alps 6%, of the NFI sample trees had damages that could clearly be linked to rockfall (Herold and Stierlin 1999). In a typical protection forest, such as the "Bannwald" of Altdorf, the proportion of damaged trees amounted to 36% (Jahn 1989). This phenomenon includes not only rockfall, but also rockslides with larger boulders, which could only be slowed down by the forest. For the study, with respect to forest effects, Gerber (1994) defines the rocks and boulders by their diameter:

Rocks		ø <0,5 meter
Small boulders	0,5 meter ≤	ø <1,0 meter
Boulders	1,0 meter ≤	ø <1,5 meters
Large boulders	1,5 meters ≤	ø <2,0 meters
Giant boulders		ø ≥2,0 meters

Forest Effects and Optimal Structure

The fundamental question now is, which rocks and boulders can still be slowed down by a forest with what type of structure? Near the town of Balzers, JAHN (1989) conducted in a pole wood suitable experiments with "relatively small rocks" that had a mass between 3 and 125 kg. At a high specific weight of 2.7 kg/dm^3, this corresponds to a regular rock cube with a side length between 10 and 36 cm. In this experiment the deposit rate of the rocks in the forest was, depending on the density of the pole wood, about two to ten times larger than on the bare control plot with the same average slope (71%).

Based on his empirical studies of rockfall events, GERBER (1994) showed that pole wood is more effective against rocks than older timber. Conversely, for small to medium size boulders, older timber is more effective than pole wood. For boulders with a diameter of more than 1.5 meters, older timber has only a small effect. Forests by themselves cannot protect against these kinds of events, no matter how they are structured.

Using a simulation model ZINGGELER (1989) studied, how a large "rock" with a dimension of 0.5 m x 0.4 m x 0.3 m and 40° slope could be slowed down by a forest. The greatest acceleration of a rock is in the first 30 meters. Consequently, the **m**ean **t**reeless **s**ection (MTS) (i.e., the distance between two tree contacts), should be less than 30 meters whenever possible. In the simulation model, especially the younger timber (mean DBH 16 cm overall respectively mean DBH 20–35 cm in the main stand) and montane plenter forests (mean DBH 20 cm, multistorey, and more than two stages of development) were able to dampen the impact velocity and rebound height. Furthermore, due to the higher mean diameter, the montane plenter forests furthermore, cause a more lateral deflection, which results in an even higher energy reduction. Montane plenter forests can also be regenerated in smaller patches (single tree selection) in a sustainable manner. Because of this, the risk of unstocked forests and critical stages of development can be avoided. Rocks in pole wood (relative thin stems, mean DBH 13 cm, mean DBH 35–50 cm in the main stand) can, however, achieve relatively high impact velocities and rebound height. The same is true for older timber (mean DBH 29 cm, mean DBH in the main stand >50 cm) because of the relative long **m**ean **t**reeless **s**ection (MTS).

Overall, the stand density, the distribution of the stocking (as short of a treeless section as possible), and the absence of gaps must be considered as the most important factors in the evaluation of the protective effects against rockfall. Depending on the diameter of the rock, the mean diameter and the diameter dispersion of the stand carry a different weight.

NFI2 Model for Forest Effects against Rockfall

The optimal stage of development with respect to forest effects depends on the rock or boulder diameter; however, the NFI did not have any information about the local rockfall incidents (diameter, frequency). Because of this, the stage of development regarding the upper stem diameter d_{dom} was not taken into account in the NFI model. Under these conditions, the "stand density index" (SDI) is the most suitable measure for protective effects in the second NFI. This is true since the SDI, in contrast to other stand density measures (No.>12 cm/ha; No.>16 cm/ha; basal area/ha; DBH sum), is mostly independent of site class, stand age, and tree species mixture (Table 5). The SDI is calculated with the help of the number of stems per hectare from those trees with a DBH larger than 12 cm and the mean diameter of the stand.

According to REINEKE (1933): $SDI = 10^{(\log N + 1{,}605 \log dg - 1{,}605)}$
or rearranged according to DANIEL and STERBA (1980): $SDI = N*(25/dg)^{-1{,}6})$
N: Number of stems per hectare, dg: Mean diameter (diameter of mean basal area tree)

Table 5. Variation of the SDI, calculated for the example spruce, based on yield tables, site classes 8 to 30.

Spruce	site class																		
	8			**16**							**20**			**24**			**30**		
stand age	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0	∑DBH	G	N_{12}	N_{16}	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0	N_0	dg_0	SDI_0
20														3800	8.2	639	2700	11.0	726
30				3789	7.7	576	25	17,7	177	0	2708	10.3	655	2130	12.9	739	1511	16.8	800
40				2376	11.1	648	121	23,0	796	237	1725	14.4	714	1339	17.7	771	966	22.6	822
50	4337	6.5	503	1591	14.5	666	157	26,2	902	510	1167	18.5	721	908	22.5	767	664	28.5	819
60	2928	8.5	521	1135	17.9	665	167	28,5	860	596	839	22.5	709	656	27.2	751	480	34.3	796
70	2102	10.5	525	846	21.3	655	164	30,0	764	594	630	26.6	696	495	32.0	735	365	40.1	777
80	1565	12.5	516	650	24.6	633	149	31,0	608	525	486	30.7	675	384	36.8	713	284	45.9	751
90	1211	14.5	507	515	28.0	617	136	31,8	492	451	388	34.8	659	307	41.5	691	228	51.7	729
100	963	16.5	495	419	31.4	603	126	32,5	409	394	318	38.9	645	251	46.3	673	187	57.5	709
110	788	18.5	487	346	34.8	587	117	32,9	346	340	263	42.9	624	208	51.1	653	156	63.3	690
120	655	20.5	477	290	38.2	571	107	33,2	290	290	221	47.0	607	175	55.9	634	131	69.2	668

N_0: Number of stems/ha (DBH >0 cm).
Dg_0: Mean diameter (DBH >0 cm) [cm].
SDI_0 Stand density index.
N_{12}: Stem number /ha ((DBH ≥12 cm).
N_{16}: Stem number /ha ((DBH ≥16 cm).
∑DBH: Sum of the diameters for all trees greater or equal 12 cm DBH per hectare [m/ha].
G: Basal area (sum of the cross sectional area at 1.3 meter height for all trees with a DBH over 0 cm, per hectare) [m^2/ha].

Based on the considerations and relationships discussed above as well as due to the inventory catalog of the second NFI, the NFI2 effect model for rockfall was limited to the following factors:

- **Stand density index** (at an 5 ar area)
- **Gaps in the stand** (equivalent to a MTS >20 meters)
- **Coverage of tree crowns less than 60%** (on a 50 x 50 meter area)

The stand density is regarded as an indicator of the palisade effects against rockfall. Stand gaps and/or low crown coverage are indicators for critical, treeless sections. Similar to the evaluation of forest effects against avalanches with the DBH sum (∑DBH), the SDI is combined with the input variable gap and crown coverage. In case of gaps and/or crown coverages of less than 60%, the effects in the NFI2 model was reduced for each by one class. Since the parameters "gap" and "crown coverage" are only available in the second NFI, conclusions about changes of the protective effects or comparisons with the first NFI must be limited to the stand density (SDI).

The interpretation or evaluation of the stand density (SDI) as a measure for the relative protective effects against rockfall was carried out in four classes with equally large ranges in values (Table 6). The classification was based on the EAFV yield tables, in particular those for spruce (BADOUX 1983). Depending on the site class and stand age, newly thinned, normally dense to loose spruce yield table stands (remaining stands) had SDI values between 477 and 822 (Table 5).

Table 6. Relative protective effect against rockfall based on the stand density (SDI).

Protective effect[1]	Stand density SDI	Comparable basal area (m^2/ha)	Control stands[2]
Low	Up to 400	Up to 18	Sparse and open stands
Medium	401–800	19–41	Normal and loose stands, thinned stands
Good	801–1200	42–65	Dense stands
Very good	Over 1200	Over 65	Very dense stands

[1] Ocular, relative assessment in the field.

[2] Based on field assessment, NFI data, yield tables, and literature, e.g. LEIBUNDGUT (1982), p. 41–43:
Peručica PF5: 65 m^2 basal area or SDI 971 (equilibrium phase, plenter phase).
Peručica PF1: 67 m^2 basal area or SDI 796 (all phases).
Peručica PF2: 74 m^2 basal area or SDI 921 (early optimal phase).
Peručica PF4: 80 m^2 basal area or SDI 1130 (late optimal phase).

The minimum and maximum values for remaining stands of the four yield tables spruce, fir, larch, and beech were between 453 (120 year old beech stand, site class 26) and 961 (40 year old fir stand, site class 26). Fully stocked, newly thinned stands, therefore, never have an SDI value of less than 400, and only on the best sites (rarely protection forests) are values sometimes over 800. The median SDI value of all NFI sample plots was 600. Based on these relationships, one class was defined with SDI values between 400–800, while the remaining classes were defined at intervals of 400.

Assuming that only forests that are denser than newly thinned stands can have a good current effect, the threshold for “good” was defined by a value of 800. Stands with an SDI under 400 are not fully stocked (i.e., the crown closure is sparse or open) and provide only relatively low protection. Only 5.6% of all NFI sample plots achieved an SDI of more than 1200. These could be stands that provided, at the moment, optimal and very good protection, but due to the high stand density, their stability is seriously threatened.

Absolute judgements with respect to the protective effects are not possible with the SDI. However, assuming that protection forests require enough light for a sufficient regeneration, the optimal sustainable density could at most be in the range of montane virgin forests during the equilibrium phase (plenter phase). For some of the virgin forests described by LEIBUNDGUT (1982), the stem number distributions in diameter classes are also published. Depending on the development stage, we have calculated SDI values between 800 and 1100 for the virgin forests of Peručica. For example, the SDI value of a virgin forest in the equilibrium phase comes to 970.

The yield-study plenter plots of the WSL have long-term mean SDI values of 595 (Jura), 613 (Alps), and 651 (Emmental). The two control plots “Dürsrüti” have long-term mean values of 744 and 826 with maximum values between 900 and 1000 (ZINGG, oral communication). It still needs to be resolved whether SDI values in the range between 600–1000, according to different site quality, are the sustainable optimum with respect to protection against rockfall in the (montane) plenter forest.

Discussion and open questions

During the preparation for the second NFI, no detailed information or facts were available about how the forest and terrain affects the rockfall. Consequently, it was not possible to assess the necessary specific data.

Today, at the end of the 1990’s, several different process models for the rockfall are being used in practical operations in order to map hazardous areas (computer simulations for an arbitrary number of defined rocks/boulders). Apart from the terrain topography, these models also account for the type of rock, soil (e.g., roughness, elasticity), and forest (DBH, No./ha). However, with respect to the effect of forests, the models are still relatively rough. Input variables are considered the number of stems per hectare and size class. With these data the mean treeless section is also calculated. Forest aisles, gaps in the stands, and especially the true distribution and clustering of trees in a stand are still not considered.

The **SDI** as a measure for the stand density, in the case of unknown relevant rock diameters, are presently, after applying it to the second NFI, also being studied in applied forestry as a relative measure for forest effects and as an absolute measure for sustainable forest structures. Additional studies need to show to what extent this measure is suitable (depending on the rockfall phenomenon) for absolute assessments with respect to actual forest effects. In this connection, other quantities (No. >16, ∑DBH, etc.) should be validated as well.

It is still an open ended question as to which diameter of the rocks/boulders what "**stand diameter**" is optimal, and which are, in each case, the suitable effect indicators (measuring quantity). At the moment it is the general consensus that the ideal rockfall protection forest should be closed and dense, but should not contain wide trees with large crowns that need a lot of room. The hypothesis is currently discussed that the ideal "stand diameter" should amount to approximately 1/3 to 1/2 of the relevant rock diameter, depending on the accepted risk and the geology. Nonetheless, the method to determine the "stand diameter" with respect to the calculations is not defined.

New insight regarding the effects of different **tree distributions** could, in principle, be gained from the following four procedures:

- Observing "silent witnesses" in rockfall forests with high rockfall intensities
- Falling boulder experiment in test areas with forest or "artificial forest" (poles)
- Falling boulder experiment with an "artificial forest" in a model of approximately 1:20 in a large laboratory
- Falling boulder simulation in a computer model (effects of different tree distribution)

In view of the **third NFI** it is important to support and assist the research in these areas. Through engaging contact between basic research and applied forestry, it is possible that the attribute catalog in the next NFI survey will contain all necessary information. It is important to record **forest structures** more differentiated and more representative of the stand as well as the stand mosaic (i.e., with the help of aerial photographs of the entire interpretation area or larger areas). Furthermore, additional information about **other parameters** from existing rockfall process models (geology, surface roughness, subsoil, rockfall material) should be assessed through observations in the field, analysis of aerial photographs, or enquiry at the forest service if these do not already exist.

3.6.3 Stability Standards in the Protection forest

Anne Herold

Apart from the current protective effects of the forest, the sustainability of the forest structure is also an important topic. The goal was to estimate whether a forest would still fulfill its function after 20 to 50 years.

This medium-term stability of forest structures is measured on five qualitative attributes of the stand constitution: the *stand structure* (horizontal and vertical), *diameter dispersion*, *crown length*, *slenderness*, and *regeneration*. These test criteria are compared on each of the sample plots to the nominal value, known as the so-called stability standards. Since the standards depend on the site, the nominal values are defined differently for each forest community.

3.6.3.1 Background

WASSER and FREHNER (1996) developed the stability standards for the most frequently occurring site types from the sub-montane up to the upper sub-alpine zone. Along the lines of this research, which is referred to in the following as "the guiding method," stability standards are used to determine a silvicultural minimum goal, which corresponds to "the minimal state of the forest that is still able to reduce the hazard in a sustainable way”. The stability standards were defined by montane silvicultural experts according to the concept of how the natural forest should be structured. This approach was chosen under the assumption that in natural forests “the risk for large-scale damages is small and the conditions for natural regeneration are good.” In this sense, minimum stability standards were defined for the following properties of the stand and differentiated according to site type:

- Mixture of tree species
- Vertical stand structure
- Diameter dispersion
- Horizontal stand structure
- Crown length or crown form of the stability support[1]
- Slenderness of the stability support[4]
- Stand (vertical or lop-sided) and anchoring of the stability support[4]
- Regeneration: germination bed, natural seeding, plants growing up

For example, the minimal stability standards are defined as follows for the “Reed grass-fir-spruce forest” (according to ELLENBERG and KLÖTZLI, 1972, forest community number 47: Calamagrostio villosae-Abietetum), which is a relatively common NFI protection forest:

– Mixture of tree species:	Fir: 30%–90% Spruce 0%–60% Larch 0%–60% Service berry: seed trees[2]
– Vertical stand structure:	Two-layer
– Diameter dispersion:	Sufficient viable trees in two different stages of development
– Horizontal stand structure:	Small cluster (spruce) and individual trees (fir)
– Crown length of the stability support:	Length at least half of the tree length
– Slenderness of the stability support:	Less than 0.8
– Stand and anchoring of the stability support:	good[3]
– Regeneration: germination bed:	Half of the area without strong vegetation competition
natural seeding:	Fir on 1/5 of the area
plants growing up:	on 1/10 of the area

Today, forest communities have been recorded in the field for only a small portion of the NFI sample plot grid. Thus, this information was calculated with a model. For each sample point, the potential natural vegetation according to BRZEZIECKI *et al.* (1993) was derived (see Chapter 3.1). This model gives, for each point of the sample plot grid, several possible forest communities with their corresponding probability of occurrence. The most probable forest community was regarded as the “valid” one and was used as the input variable for the stability standard determination. Since the probabilities of occurrences were between 12% and 100% (with a median of 55%), this input variable includes a considerable uncertainty.

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[1] Stability supports are either the strongest individual trees in the upper layer (structure trees); trees that stand close to each other and that depend on each other, and whose crown length is up to three-quarters of the tree length (small cluster); or trees that stand close to each other and have a common crown surface and whose crown length totals three-quarters or more of the tree length.

[2] At least as many service berry trees that are needed to perpetuate the species.

[3] All trees are vertical and have strong, deep roots; the soil is appropriate for the present species so that the roots can easily penetrate the soil.

3.6.3.2 Study Regarding the Fulfillment of the Stability Standards

The stability standards according to WASSER and FREHNER (1996) were compared with forest structures found on each of the sample points. The more the attributes of the forest structure (i.e., test criteria) fulfilled these standards, the higher the rating was for the medium-term stability of the forest structures.

Several different problems arose during this application. The NFI attributes “stand structure” and their outcomes were rarely defined as stability standards in the guiding method and were, therefore, rarely directly applicable. In order to come as close as possible to the definition of the guiding method, several different attributes had to be combined differently for each attribute outcome (see also Table 7 or 9).

The NFI does not have any information about the anchoring of the stability support, germination bed, and natural seeding. The tree species mixture and the stability support were not assessed at the stand level, but originated from the $200\ m^2$ and $500\ m^2$ sample plots. This fact, and the uncertainty of the modeled natural potential vegetation, required some modifications and simplifications in the model for the stability standards.

Table 7. Minimum stability standards with respect to the vertical (structure) and horizontal (crown closure) stand structure. Required variable combinations by forest community.

Forest community	Minimum stability standards in respect to:			
(EK No.)		STRUCTURE	AND	CROWN CLOSURE
1–17 OR 21–32 OR 38–41 OR 43–45		>0	AND	>1 AND ≠ 6
18–20		2	AND	>2
	OR	>2	AND	>1
46–47		>1 AND <4	AND	>1
	OR	4	AND	>0
48–53 OR 56–60		2	AND	>2
	OR	3	AND	>1
	OR	4	AND	>0
54 OR 55		<3	AND	>2
	OR	3	AND	>1
	OR	4	AND	>0
33–37 OR 42	OR	>4	AND	<4 AND >7
>60	OR	>0	AND	>0

Meaning of code STRUCTURE:
1 = One layer
2 = Multi-layer regular
3 = Stratified
4 = Cluster structure

Meaning of code CROWN CLOSURE:
1 = Crowded
2 = Normal
3 = Open
4 = Open/sparse
5 = Sparse
6 = Grouped/crowded
7 = Grouped/normal
8 = Complete

As the most important modification, the test criterion “tree species mixture” had to be relinquished. The reasons for this are first, the mixture proportion depends very much on the site. Information about the forest community, which describes the site has to be very precise, so that the mixture proportion can be compared with appropriate standards. However, this was not the case as it was previously discussed. Second, the mixture must be derived from the tree data in the sample plots, since it is not known in the NFI at the stand level. The size of the sample plot ($200\ m^2$ and $500\ m^2$), however, is not large enough to reliably estimate the proportion of different tree species. This is not the case for the slenderness or the diameter dispersion, which are calculated as the mean (or maximum-minimum difference) of continuous quantities (DBH, tree height) for all trees on the sample plot.

In the above mentioned example, the standard with respect to mixture is “at least 30% fir, maximal 60% spruce and maximal 60% larch.” Even in a stand where such mixture exists, it is not guaranteed that it is present on the 500 m^2 sample plot, since the trees are not evenly distributed and this area is too small.

Detailed information about the NFI definition of the minimal stability standards for the five test criteria are presented in Tables 7 to 11. The interpretation of this is discussed in the following with the help of the above mentioned example of the “Reed grass-fir-spruce forest” (according to ELLENBERG and KLÖTZLI (1972) forest community number 47: “wood reed-fir-spruce forest”).

In this example, the stand should not be single-layered with respect to vertical and horizontal **stand structures**. If the stand is multi-layered, the canopy cover density should be anything but crowded, and if the stand has a cluster structure, the canopy cover density is not relevant (Table 7).

Since the **diameter dispersion** is estimated on the sample plot (500 m^2), standards are only meaningful for coniferous forest communities of the upper montane, oreal, and subalpine zones, as long as the stand is either one or multi-layered (WASSER 1997, oral communication). Over a larger area, layered stands have a sufficient diameter dispersion and clusters are stable even without a diameter dispersion. In our example, the difference between the largest and the smallest DBH should at least total 15 cm if the stand is single-layered. The difference is unimportant if the stand is layered or clustered (Table 8).

Table 8. Minimum stability standards with respect to the diameter dispersion. Required diameter difference by forest communities.

Forest community (EK No.)	Minimum stability standards: $DBH_{max} - DBH_{min}$ [1]
1–45	≥0 cm
46–60 AND (stratified OR cluster structure)	≥0 cm
(46–52 OR 54–58 OR 60) AND layered structure	≥15 cm
(53 OR 59) AND layered structure	≥25 cm
>60	≥0 cm

[1] Because this should be the diameter dispersion of the “viable trees,” sample trees that are slightly one-sided or have short crowns (<1/4 of the tree length); those that are strong one-sided and have short crowns; and those that are strong one-sided and have medium crowns (<1/2 of the tree length) are not considered.

The mean **slenderness** of trees in the upper layer must be less than 0.8 (Table 9). In the subalpine zone, the **crown length** is usually required to be at least 2/3 of the tree length. In the NFI this information is unknown. The classification of the crown length goes down only to half of the tree length, which is not a sufficient limit for subalpine forest communities. This problem can be circumvented by requiring a higher standard with respect to the slenderness of the stability supporting trees in these forest communities (apart in the clustered stands), since crown length and slenderness are highly correlated. In our example, at least half of the upper layer trees must have long crowns (crown length amounts to at least half of the tree length) (Table 10).

In our example, the **regeneration** had to cover at least 10% of the interpretation area (2500 m^2) (Table 11).

Table 9. Minimum stability standards with respect to slenderness. Required maximum mean slenderness of the stability support[1] by forest communities.

Forest community (EK No.)	Minimum stability standards: Avg(BHOHD/DBH)
1–47 OR 49–52 OR 54–56	<0.8
(48 OR 53 OR 57–60) AND cluster structure	≥0
(48 OR 53 OR 57–60) AND (layered OR stratified structure)	<0.7
>60	≥0

BHOHD: Estimated tree height [meters].

BHD: Diameter at breast height [cm].

[1] Stability support: Only trees of the **upper layer** are included.

Table 10. Minimum stability standards with respect to the crown. Required crown form or length of the stability support[1] by forest communities.

Forest community	Minimum stability standards:	
(EK No.)	CROWN LENGTH	CROWN FORM
1–17 OR 21–32 OR 38–41 OR 43–45	–	3 for ≤50% of all trees
18–20	1 for ≥50% of all trees	–
46–60	1 for ≥50% of all trees Bäume	–
33–37 OR 42 OR >60	–	–

Meaning of code CROWN LENGTH:	1 = Crown length >1/2 of the tree length.
	2 = Crown length 1/2–1/4 of the tree length.
	3 = Crown length <1/4 der of the tree length.
Meaning of code CROWN FORM:	1 = Round
	2 = Slightly one-sided, average
	3 = Strong one-sided

[1] Stability support: Only trees of the **upper layer** are included.

Table 11. Minimum stability standards with respect to the regeneration. Required regeneration coverage by forest communities.

Forest community (EK No.)	Minimum stability standards: REGENERATION COVERAGE:
1–32 OR 35–41 OR 43–45	≥1%
46–58 OR 60	≥10%
59	≥1%
33–34 OR 42	1%–75%
>60	≥0%

Result of the Stability Standards

With the help of the proportion of fulfilled and unfulfilled stability standards, a simple measure for the structural sustainability was generated for each of the samples. The more standards that were fulfilled, the better the medium-term stability of the forest structures was rated. BRÄNDLI and HEROLD (1999) classified the proportion of fulfilled stability standards in three parts: “less than a third,” “between one and two-thirds,” or “more than two-thirds.”

3.6.3.3 Discussion

1. The stability standards of the guiding method are based, even today, on expert opinion. The actual median-/long-term structural development of the stands assessed and treated with this method is (still) not completely verified.
2. The assessed attributes with respect to the stand structure in the first and second NFI were not defined for this purpose, and the suitability was very limited as well (see also the discussed problem of the crown length). In particular, more refined assessments of the regeneration situation (in the montane forest) and the tree species composition in the stands were missing in the second NFI.
3. It is not sufficiently accurate to deduce the stand structure from the tree data of the 500 m^2 sample plot, since this area is too small to assess correctly certain structural attributes in certain forest communities.
4. The model for the evaluation of the stability standards would be more meaningful if information about the site type (forest community) would be assessed in the field.

3.6.4 Literature

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