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FOREST MANAGEMENT DECISION SUPPORT FOR ROCKFALL INFLUENCED FORESTS IN ALPINE REGIONS

ENTSCHEIDUNGSMODELL FÜR DIE WALDBAULICHE BEHANDLUNG STEINSCHLAGBEEINFLUSSTER SCHUTZWÄLDER IM ALPENRAUM

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ABSTRACT

A decision support tool evaluating the protection function of rock fall influenced forests is presented. The tool can be applied on the forest stand scale and incorporates estimates for tree-boulder collision probability and for energy dissipation potential along the rock fall trajectory. By coupling these tools with the forest growth model PROGNAUS, which has been re-parameterised to rock fall influenced forests, these estimates can evaluate present and future forest protection effect. A spatially explicit database realised within ESRI ArcView structures the assessed data and enables a sound platform for these tools and data storage, analysis and performance monitoring can be easily performed.

Keywords: rockfall, protective forest, decision support

ZUSAMMENFASSUNG

Ein Entscheidungsmodell zur Bewertung der Schutzfunktionalität steinschlagbeeinflusster Wälder wurde entwickelt. Dieses Modell arbeitet auf Bestandesebene und kombiniert Bestandeswachstum, Trefferwahrscheinlichkeit und Energiedissipation zu einer dynamischen Bewertung der Schutzeffizienz des untersuchten Bestandes. Dabei können unterschiedliche waldbauliche Behandlungsalternativen dynamisch berücksichtigt werden. Das Entscheidungsmodell ist räumlich explizit in MS-Access und ESRI ArcView realisiert und ermöglicht so eine effiziente Datenerhebung, Bewertung, Präsentation und Erfolgsanalyse von schutzwaldbaulichen Projekten.

Schlagwörter: Steinschlag, Schutzwald, Entscheidungssysteme

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INTRODUCTION

Many areas in the European Alps heavily rely on the protection capacity of mountain forests against rock falls and snow avalanches. In Austria and Switzerland each year approximately 50 mill. Euros are spent for maintenance and improvement of protection function provided by mountain forests (CIPRA, 1996). In Austria forests are declared protection forests, when special treatment is needed to prevent erosion, de-forestation, mass movements or other natural hazards. These protection forests can be subdivided into forests securing objects and into forests providing socio-economic function and protection against natural hazards by maintaining themselves (Mauser, 1997). Within the broad range of mass movements having impact on mountain forests we want to focus on rock fall processes, which are defined in this paper as quick movement of individual elements, their propagation being independent on each other as their main driving force is gravitation only (Selby, 1993).

DECISION PROCESSES IN FOREST MANAGEMENT

When setting out management plans for mountain forests, foresters have to take many objectives into consideration. For example they have to consider production alternatives, biodiversity conservation, recreation and protection function. Therefore the process of forest management planning can be seen as a multi-criteria-decision problem, where paramount goals are needed to develop sound management decisions. Such goals and their relative importance can be defined by external objectives (Vacik & Lexer, 2001), or they can be defined based on evaluation of socio-economic values which are internalised to market values (Strange et al., 1999). Also sustainable forest management can be defined as the major objective, which allows for easy combined evaluation of market and non-market values (Varma et al., 2000). Despite the fact that there is no universally accepted definition for sustainable forest management, according to Varma (1999) and Maser (1994) the following criteria can help in measuring sustainability in each of the individual planning sections: (i) biological diversity, (ii) forest health and vitality, (iii) productive function, (iv) protective function, (v) economic and social needs. We consider criteria (i), (ii) and (iv) for rating efficiency and sustainability of mountain forest protective function.

Decision support systems (DSS) can be seen as computer based systems for integrating (i) data base management systems with (ii) analytical and operational models, (iii) graphic display, (iv) tabular reporting capabilities and (v) expert knowledge of decision makers to assist in solving specific problems (Fischer et al., 1996). These capabilities can be easily realised within a Geographical Information System (GIS). We will focus on a GIS based DSS concept, which evaluates forest structure, its adaptation, resistance and sustainability against rockfall processes in a quantitative way.

REVIEW ON RESEARCH ON THE INFLUENCE OF ROCKFALL ON FORESTS

Despite the fact that much practical experience exists in the Alps in managing rock fall protective forests, there is so far only limited knowledge available focusing on process dynamics and forest ecosystem adaptation to rock fall activity (Dorren, 2002). Most rock fall assessment techniques utilise simulation tools originally designed for rock slopes or vegetation-free hill slopes. Such techniques assume distinct rock fall sources, constant boulder sizes and boulder trajectories which are not influenced by trees, wooden detritus or other obstacles. Such tools neglect non-point rock fall sources, soft forest soil and ground vegetation with variable but high energy dissipation capacity, which is often typical for rockfall sources in forested areas (Hoesle, 2001).

Influence of rock fall activity on forests

Despite the fact that vegetation effects can initiate rock fall by weakening the bedrock along partings by root force and animal or human action, several studies show that mountain forests reduce rock fall impact and minimise run-out distance of detached boulders to a great extent (Jahn 1988; Gsteiger 1989; Gerber, 1994). Dissipative effects of forest stands are manifold: (i) full stem contact with adsorption of up to 80 % of the boulders kinetic energy, (ii) half stem contact with variable energy adsorption and boulder deflection, (iii) contact with shrubs, ground vegetation, (iv) high dampening capacity of forest soils due to bio-activity, microclimate and vegetation detritus, (v) high surface roughness due to vegetation and dead wood (Gsteiger, 1989). These effects result in higher energy dissipation, which can be expressed geometrically as the "friction slope", the gradient between the starting and the stopping point along the rock fall trajectory (Meissl, 1996). Whereas non-vegetated slopes typically show friction slopes between 32-34°, on vegetated hillslopes gradients between 35-38° can be observed (Meissl, 1996). Based on field studies Gsteiger (1989) concluded that hillslopes with a gradient more than 30° constitute potential rock fall source areas, whereas hillslope sections with less than 30° constitute depositional areas.

It is known from various studies that detached boulders can approach their maximum energy level after a travel distance of 30 m (Bozzolo, 1987; Jahn, 1988). Therefore the dissipative effect of vegetation should take effect within this distance (Gsteiger, 1989; Hoesle, 2001). Jahn (1988) compares rock fall trajectories at the same test site with and without forest vegetation and reports that in forest stands deposition rate can be four to ten times the rate of non-vegetated trajectories. For full tree contact Jahn (1988) re-calculated an energy dissipation of 80% with 40% of the boulders being immediately stopped after impact.

Statistical analysis of the data set of the Austrian National Forest inventory was carried out by Vospernik (2002). The study concluded that rock fall damage probability and thus protection efficiency, is positively correlated to stand density and equal tree distribution. The investigated mountainous stands and among them especially mixed forests show equally distributed young stands and aggregated mature stands with strong diameter differentiation. Rockall damage is 47 % higher on calcareous soils, which are steeper compared to other lithologic settings. Once damaged, the probability for a tree to die within the next six years is 66 % higher compared to vital individuals and thick barked species, such as larch, which shows significantly lower damage probability (23%). Therefore where possible, mixed forest stands consisting of mature, damage tolerant individuals which can face high energy impacts, and dense, young tree groupings which can mitigate frequent but extensive low energy impacts, are preferred rock fall shelter forest structures. As full vegetation cover is favoured, non-vital trees or trees possibly initiating rock fall are cleared carefully.

The lack of process knowledge becomes evident when combined measures are applied, which need quantitative assessment techniques. Punctual shelter of objects can be carried out relying exclusively on technical protection structures, such as rock wall stabilisation or retarding structures in the run-out zone (dams or flexible nets). For most protection forests a combination of technical and forest treatment measures can be applied. As the management of protection forests is expensive and time consuming, a tendency for applying minimal treatment measures is obvious and priority rating indices and clear recommendations for minimal treatment measures are needed from the practitioner's point of view (BUWAL, 1996).

CONCEPT OF THE DECISION SUPPORT TOOL

For sound protection forest management not only forest stand features have to be mapped, also the rockfall process itself and its individual character needs to be evaluated. Therefore the tool is structured into three sub-tools:

> Tool 1: A forest stand sampling design, combining forest stand and geomorphic parameter assessment (boulder size distribution, geologic setting, process initiation, extent of rockfall trajectory) is dynamically linked to a digital forest map.
>
> Tool 2: Based on database information on forest stand density, average tree diameter dbh_g and volume V_d, boulder size distribution and boulder trajectory location, the boulder impact probability and energy dissipation during impact are estimated on the stand scale.
>
> Tool 3: A forest growth model can be linked to tool 2 which enables dynamic evaluation of forest stands protection effect by considering forest stand development or forest tending measures.

Due to the rather extensive character of protection forest management, the tool works on a local to regional level, by utilising a spatially explicit database implemented in MS-Access and ESRI ArcView 3.2.

Inventory design

The inventory concept incorporates site and forest stand parameter, as well as geologic and geomorphologic information. Assessment units are structured according to "rockfall catchment areas", to enforce a clear linkage of forest parameters to rockfall sources and corresponding depositional areas. The rockfall catchment area is defined as the interconnected area of rockfall source zone, transition zone and deposition zone (Zinggeler, 1989), which is strongly depend on surface morphology.

In a first step (pre-analysis) the investigated area is structured into homogenous sub-units based on geomorphology and ecosystem type. In a second step (sub-unit analysis), for each sub-unit transect sampling inventory (see figure 1) is carried out. Five 300 m² sampling plots aligned on a vertical line, each of them separated by 20 m are set out along rock fall trajectories. For each plot site, stand, individual tree and rock fall parameter are assessed (see table 1). As sampling plots are regarded as a full inventory, they can be easily compared to each other and the changes with increasing distance from the rock fall source can be estimated. As the parameter database is directly linked to the geospatial database of the field mapping data, further analysis steps can be carried out in a spatially explicit way.

Table 1: Forest and geomorphologic parameters assessed by transect sampling.

Parameter group	Parameter	Assessment area
Site parameter	Elevation, slope gradient, exposition, relief, vegetation cover percentage, etc.	Transect area
Geomorphological parameter	Soil, humus layer, moisture, meso/micro relief, rock deposit size percentage, rockfall source, etc.	Transect area
Stand parameter	Growth district, ecosystem type, growth phase, etc.	Forest stand
Tree parameter	Species, dimension (diameter, height, crown height), layer, location of tree, vitality, growth shape, tree damages, rock deposits at base, etc.	R = 9,77 m A = 300 m²
Regeneration parameter	Species, status, optimum, necessity, repression, cause of repression, etc.	R = 1 m A = 3,14 m²

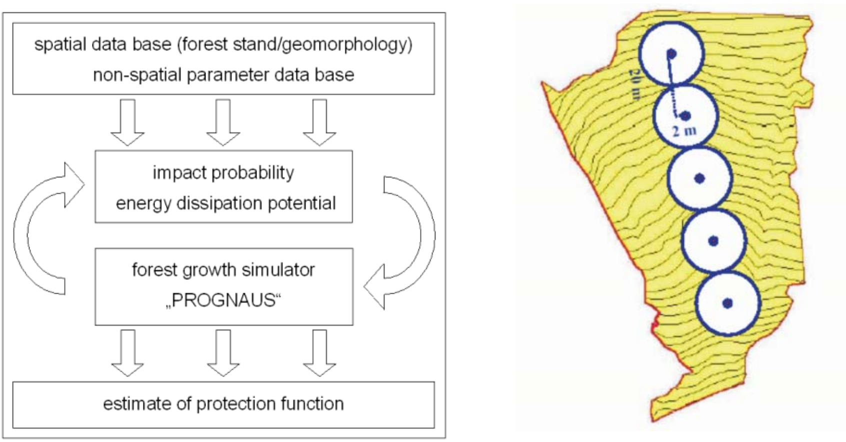

Figure 1: Left: Structure of the decision support tool. Right: and transect inventory design.

Estimation of tree-boulder impacts

The relative dissipative effect of single trees can be assessed by estimating the probability for tree-boulder contacts along the boulder travel length (Gsteiger, 1989). This can be achieved by taking the following parameters into consideration: (i) number of trees, (ii) tree basal area, (iii) tree diameter distribution or average tree diameter dbh_g, (iv) boulder diameter distribution or average boulder diameter (Jahn, 1988; Gsteiger, 1989).

Based on detailed investigation of five forest stands Gsteiger (1989) conceptualised the index "average distance till contact" (ADC) (Eq. 1). When splitting up the forest stand into vertical corridors of a width equal to the boulder diameter, the quotient between the summed corridor length and the average number of tree hits results in the **A**verage **D**istance between tree **C**ontacts (ADC). Though this index is interpreted as the mean average distance between tree contacts, it rather underestimates the impact probability. Therefore, according to Berger et al., (2002), the ACD should be reduced by 10 %. This can be deducted from field experiments and the fact that tree basal area and boulder trajectory need to overlap by 10 to 20 % to result in a significant impact.

$$ADC = \frac{A}{\left[(N_A \times B) + \sum_{i=1}^{N_A} dbh \right]} \tag{1}$$

A...forest stand area [m²]
N_A...number of stems [-]
B...boulder diameter [m]
dbh…stem's diameter breast height [m]

Based on the ADC concept of Gsteiger (1989) a new index is conceptualised, which estimates the collision probability of rock fall boulders along boulder travel distance. It assumes a forest stand structured into horizontal lines of trees, each having an average inter-tree distance *a*. Under these assumptions P_{la} gives the general formulation of the passing probability of row *l* after a travel distance l*a (Eq. 2) assuming independence between the rows as the boulder arbitrarily modifies its direction after each ground impact.

$$P_{la} = \prod_{i=1}^{N_A} \left(1 - \frac{dbh_g + B}{a - dbh_g} \right) \tag{2}$$

$$with, \quad a = \sqrt{A / N_A}$$

A...stand area [m]
N_A...Number of trees in stand [-]
a…distance between trees [m]
l…row number [-]
dbh_g... mean stem diameter [m]
B...boulder diameter [m]

The horizontal travelling distance where the passing and impact probability are equal (50 %) is called the average impact distance D_p and is consistent with the ADC (see figure 2). Distances corresponding to higher probability percentiles give an estimate of the impact travel length with lower error probability. The D_p corresponds to 40-50 % of the ADC, which is consistent to the discussion given above.

Estimation of energy dissipation during tree impact

As detailed information on tree-boulder impact, such as impact height, impact type, boulder shape is not known, only a simple approach such as the calculation of fracture energy of the tree is feasible. Therefore a rough estimate of the energy needed to fracture a tree can be calculated by considering the ADC or $D_{p,}$ the stand's depth and the fracture work consumed by an average tree.

As it is frequently reported that trees frequently break at their upper third due to strong oscillation after a boulder contact it can be assumed that the whole stem is adsorbing the impact energy. Therefore the fracturing work W_{Tree} can be calculated according to Eq. 3., considering the volume of the stem and the unit fracture energy U_{frWood}. U_{frWood} is calculated based on the wood's stress-stain relation derived from laboratory bending tests of fresh wood (Berger et al., 2002).

In order to estimate the dissipative efficiency of a forest stand after a given travel length, the stand dissipated energy line E_{stand} (Eq.4) and the boulder energy line $E_{boulder}$ (Eq. 5) can be plotted against the travel distance. At the travel distance where both lines cross, the boulder's kinetic energy can be fully dissipated by fracture work of the stand assuming full impacts only. This travel distance is called dissipative or plunge length.

$$W_{dbh} = V_d U_{frWood} \tag{3}$$

$$with,\ U_{frWood} = \int_0^{\varepsilon_{fr}} E_{wood} d\varepsilon_{fr}$$

V_d…stem volume [m³]
U_{frWood}… unit fracture work [J/m³]
E_{wood}…young modulus of fresh wood [N/mm²]
ε_{fr}…stain of fresh wood [N/mm²]

$$E_{disp} = \tfrac{D_{path}}{D_p} W_{dbh} \tag{4}$$

$$E_{boulder} = mg(\tan\alpha - \tan\xi_e)D_{path} \tag{5}$$

E_{disp}…dissipated energy potential after distance D_p [kN]
D_{path}…boulder travel length [m]
D_p…impact distance [m]
m…boulder mass [N]
g…gravity [m/s²]
α…slope gradient [°]
ξe…rockfall energy line [°]~32-34°

Dynamic assessment of forest growth

PROGNAUS is an individual tree growth model. In has been developed based on data from the Austrian National Forest inventory (ANFI), which also assesses rock fall damage. PROGNAUS consists of four components: (i) diameter and height increment model (Monserud & Sterba, 1996; Hasenauer & Monserud, 1996; Schieler, 1997), (ii) mortality model (Monserud & Sterba, 1999), (iii) in-growth model (Ledermann, 2002), (iv) new rockfall damage model based on existing damage (Vospernik, 2002). Based on rock fall influenced sub-sets of the Austrian National Forest Inventory the sub-models (i), (ii) and (iii) were re-parameterised (Vospernik, 2002). The model validation is carried out based on four assessed rock fall forest sites. All re-fitted models of PROGNAUS perform well (Vospernik, 2002). With these simulators stand development can be extrapolated and reaction to treatment measures can be evaluated.

EXAMPLE

All three tools are applied to one sample stand in order to assess the shelter efficiency in 2001 and 50 years later in 2051, assuming no additional tending measures in between. The test site is located at Falkenstein, Upper Austria, at an elevation between 500-740 msl, with a mixed forest structure consisting of spruce, fir and beech (Hoesle, 1997). At an average slope of 43°, the site is exposed towards southwest. Stand growth is simulated for 2001 and 2051 and the ADC and D_p are calculated for these years for boulder diameters 0.3 and 0.5 m. Stand parameter and results are given in Table 2. When considering the advisable distance between individual tree collisions of 30 m (Gsteiger, 1989), table 2 indicates very unfavourable conditions for both indices. The D_p results in slightly shorter impact distances. Noticeably both indices result in longer impact distances when considering smaller boulder diameters. Figure 2 shows that dense stands are more sensitive to boulder diameter changes, whereas stands with larger tree diameters result in shorter impact distances. However the residual probability of no impact at all, is constantly around 5 % regardless on forest stand type.

Table 2: Comparison of average travel distance D_p and maximum travel distance ADC for stand growth simulations for the years 2001and 2051. Index 30 and 50 denotes a boulder diameter of 0.3 and 0.5 cm.

	Years	
	2001	2051
N [N/ha]	500	430
dbhg [m]	0,075	0,14
ADC30[m]	53,33	54,11
ADC50 [m]	34,78	37,20
Dp30 [m]	49,19	44,30
Dp50 [m]	32,00	31,00

Figure 3 shows that the kinetic energy line of the 0.5 m boulder is clearly above the stand's dissipation potential in 2001 and 2051. In 2051 the 0.3 m boulder the stand's dissipation potential will be sufficient despite the fact that the ADC or D_p still state unfavourable conditions. Under extrapolation of the actual stand development conditions it can be concluded that the stand's resistance will improve steadily. Whereas at the moment no sufficient protection function is to be expected, in 2051 boulders up to 0.3 m diameter will be stopped to a high percentage within reasonable distance.

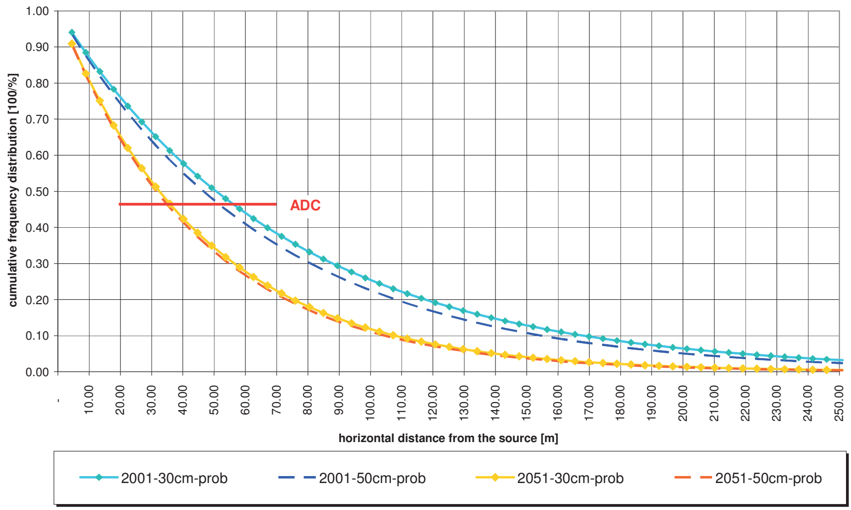

Figure 2: Cumulative probability distribution of distances till the first tree-boulder impact for test site Falkenstein, sub stand 8. The calculation is performed for 2001 and 2051 for boulder diameter of 0.3 and 0.5 m. The ADC of this stand constantly equals the 47th percentile. The 50th percentile of the distribution (D_p) is therefore comparable to the ADC.

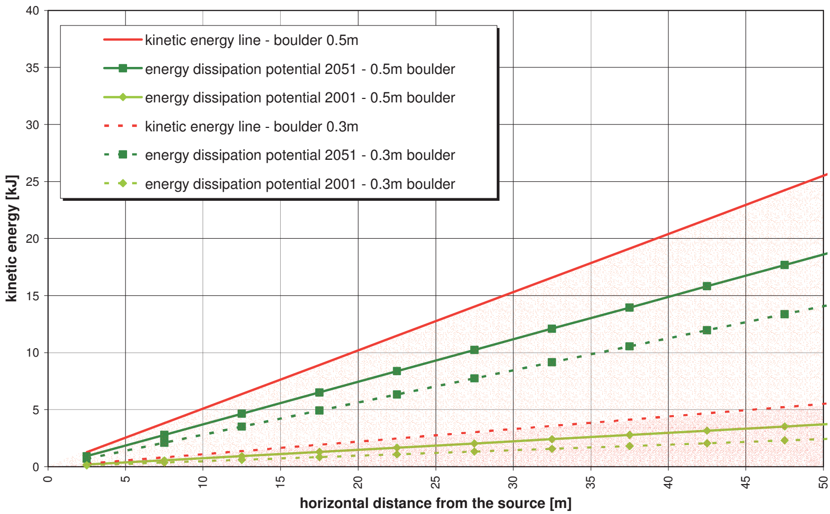

Figure 3: Estimation of the travel length needed to fully dissipate the boulder's kinetic energy by tree impacts. In 2051 the kinetic energy of a 0.3 m boulder can be dissipated by the stand as the dissipation potential clearly exceeds the kinetic energy of the 0.3 m boulder.

DISCUSSION AND OUTLOOK

By considering sustainability as the paramount goal for management decisions of protection forests, the forest's protection effect can be evaluated based on ecosystem diversity, stand vitality and protection function. Decision support systems for defining appropriate management measures can be based on these objectives. To enable this, a decision support tool has been developed which incorporates two sub-tools: (1) forest and rockfall parameter assessment, and (2) evaluation of protection effect of forest management alternatives. The first tool consists of a two-step assessment procedure, which delineates sub-stands based upon homogeneous forest types, rockfall parameters and rockfall run-out zones and applies transect sampling for each of these sub-stands. This procedure allows for sound and efficient analysis of the mutual interrelations between rockfall process and forest stand development. As all assessed parameters are structured in a spatially explicit database, they can be easily accessed by other tools such as forest growth, rockfall trajectory simulation and protection effect estimation. The second tool is realised by combining stand growth modelling with the evaluation of boulder-tree impact probability and impact energy dissipation potential.

To evaluate impact probability a concept resulting in a cumulative probability distribution of distances till the first boulder-tree contact is conceptualised. It is based on the ADC concept of Gsteiger (1989) but extents it, as the average distance between boulder tree contacts D_p and distances of different (error) probability can be given. This allows for sensivity analysis (see figure 2). D_p, the 50th percentile of the cumulative distribution gives the average distance and is therefore comparable to the ADC. Both indices (ADC, D_p) relate boulder size, tree diameter and number of trees against the trajectory length. Therefore they estimate impact probability but no energy dissipation capacity which additionally needs information on boulder and tree volume. When considering only these indices, bigger boulders may result in shorter distances and thus more impacts, which do not necessarily have to reflect better protection effect. As the whole tree diameter distribution is considered for these indices, also the boulder size distribution should be considered and not only the design boulder size. As the design boulder rather represents an upper limit of the boulder size distribution, it tends to overestimate. Despite these limitations both indices do give reliable results as field evidence does show (Berger et al., 2002). Thus they can serve as estimates of impact probability.

In this respect an index based on the fracture work per unit volume of fresh wood is introduced, which only relies on easily available stand parameters. By combining this index with D_p or ADC, the boulder's run-out distance till the kinetic energy is fully dissipated by stand fracture work can be estimated. This enables a direct comparison with physically based rock fall trajectory models and technical retention concepts (Bozollo, 1987; Hoesle, 2001). As figure 3 shows, the dissipation potential of the stand clearly performs better for smaller boulder sizes, despite the fact the ADC or D_p are significantly longer (see table 2),. This is due to the fact that the boulder's kinetic energy is mainly dependent on the boulder's volume, whereas the impact probability depends on diameter relation. As the index assumes full impacts only, it gives a relative estimate of the dissipation energy potential and should be utilised for comparison purpose only.

The calculation of this relative energy dissipation potential only considers the dissipation potential at one point of time. The combination of this estimate with a growth model adapted to protection forests, such as PROGNAUS (Vospernik, 2002), allows for dynamic evaluation in time domain. By recursively calculating stand parameter change and corresponding dissipative length variation, the effect of tending measures can be estimated (see figure 3), which significantly extents the decision support functionality of the tool towards the comparison of different management alternatives and priority rating of measures to be implemented.

However, we must be aware that these tools are only a first step, as their applicability has been proofed only for equally distributed forest stands. The applicability of this concept should be also extended to other stand patterns. As it is commonly known that especially young tree groupings and shrubs can serve as efficient rockfall shelter, they should be incorporated into this concept (Hoesle, 2001).

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REFERENCE

Berger et al., (2002) ROCKFOR – Rock fall forest interrelations, Second annual report. *EC Funded project QRLT-1999-31902*, Cemagref, Grenoble.

Bozzolo, D. (1987) Ein mathematisches Modell zur Beschreibung der Dynamik von Steinschlag, *PhD Thesis Nr 8490*, ETH-Zuerich.

BUWAL, (1996) Wegleitung minimale Pflegemaßnahmen für Wälder mit Schutzfunktion“, *BUWAL,* Berne 1996.

CIPRA, (1996) Mountain Forest Protocol of the Alpine Convention, CIPRA, Schaan.

Dorren, I., (2002) Mountain Ecosystems – GIS modeling of rockfall and protection forest structure, *PhD Thesis*, Univ. Amsterdam, 164 pp.

Fischer, M.M., Scholten, H.J., Unwin D., (1996) Geographic information systems, Spatial Data Analysis and spatial modelling”. *In: Fischer, M.M., Scholten, H.J., Unwin, D., (Eds.), Spatial Analytical Perspectives on GIS. GISDATA Series No. 4*, Taylor and Francis, London, pp. 3-19.

Gerber, W., (1994) Beurteilung des Prozesses Steinschlag, *Swiss Task Force Natural Hazards (FAN), Course from 20-22. October 1994*, Potschavio.

Gsteiger, P. (1989) Steinschlag Wald Relief Empirische Grundlagen zur Steinschlagmodellierung, *Diploma Thesis Geography*, Dep. Of Geography, University of Berne.

Hasenauer, H., Monserud, R.A., (1996) A Crown model for Austrian forests, *For. Ecol. And Managm.* 84, 49-60.

Hoesle B., (1997) Finkenberg-Einödseite: Aufbau und Realisierung eines Analysesystems zur Standortsspezifischen Behandlung von Sanierungsbedürftigen Wäldern in Bezug auf den Wirkungsbereich der Naturgefahr Steinschlag, Institut für Wildbach- und Lawinenschutz, Univ. für Bodenkultur.

Hoesle, B., (2001) Rock Fall Problems and its Protection-Course script, Department of Civil and Structural Engineering, The Hong Kong Polytechnic University.

Jahn, J., (1988) Entwaldung und Steinschlag. *International Congress INTERPRAEVENT 1988 – Graz, Proceedings,* 1, 185-198.

Ledermann, T., (2002) Ein Einwuchsmodell aus den Daten der österreichischen Waldinventur 1981-1996, *Cbl. ges. Forstwesen*, 119, 40-76.

Maser, C., (1994) Sustainable Forestry: Philosophy, Science and Econnomics. *St. Lucie Press*, Florida.

Mauser, H., (1997) Die Verwendung des Luftbildes bei Inventuren im Schutzwald mit besonderer Berücksichtigung photogrammetrischer Messungen an Einzelbäumen zur Beurteilung von Entwicklungsphasen, *PhD Thesis*, University of Agricultural Sciences. Vienna.

Meissl, G., (1998) Modellierung der Reichweite von Felsstuerzen, *Innsbr. Geogr. Studien*, 28, Inst. für Geogr. , Univ. Innsbruck, 169pp.

Monserud, R.A., Sterba, H., (1996) A basal area increment model for individual trees growing in even- and uneven aged forest stands in Austria, *For. Ecol. and Managm.* 80, 57-80.

Schieler, K., (1997) Methode der Zuwachsberechnung der Österreichischen Waldinventur, *Dissertation*, University of Agricultural Sciences Vienna.

Selby, M.J., (1991) Hillslope Materials and Processes", *Oxford University Press*, Oxford.

Varma, V.K., Ferguson, I., Wild, I., 2000. Decision support system for sustainable forest management. *For. Eco. and Managm.*, 128, 1-2, 49-55.

Vospernik, S., (2002) Predicting forest growth against rockfall, final report, *Institute of Forest growth and Yield*, University of Agricultural Sciences Vienna.

Zinggeler, A., (1989) Steinschlagsimulation in Gebirgswäldern Modellierung der relevanten Teilprozesse, *Diploma Thesis,* Dep of Geography, University of Berne.