GEOGRAFICKÝ ČASOPIS / GEOGRAPHICAL JOURNAL 61 (2009) 1, 19-28

BIOGEOMORPHIC EFFECTS OF TREES ON ROCK-MANTLED SLOPES: SEARCHING FOR DYNAMIC EQUILIBRIUM

Pavel Raška, Tomáš Oršulák*

* Department of Geography, Faculty of Science, J. E. Purkyně University, České mládeže 8, 400 96 Ústí nad Labem, Czech Republic, pavel.raska@ujep.cz, tomas.orsulak@ujep.cz

Biogeomorphic effects of trees on rock-mantled slopes: searching for dynamic equilibrium.

Slope development remains one of the central points of geomorphological research, which results in a continuing discussion about concepts proposed by classics of geomorphology (Davis, Penck, King, etc.) on the one hand, as well as in new methodical approaches applied to the study of slopes in concrete environments on the other. The research presented applies the biogeomorphological methods and concept of non-linearity in the assessment of short-term dynamics of the middle segment of rock-mantled slopes in the protective forests. In contrast to general concepts, it is shown that even in the mid-slope, where the permanent prevalence of denudation is usually assumed, the bioprotective and bioerosive effects of trees (trunks) may cause significant variations in the balance between accumulation and denudation.

Key words: slope development, tree trunks, biogeomorphology, nonlinear dynamics, Czech Middle mountains

INTRODUCTION

The problem of slope development has been in the centre of geomorphological interest since its foundation as a modern scientific discipline in the late 19th century. That is due to the fact, that slopes represent the most common landform and to understand their development is a crucial point in seeking the principles of evolution of a landscape as a whole (cf. Summerfield 1991). Therefore, the specialized and applied research has often been closely related to the formation of theoretical concepts and educational models.

Starting with a classical one proposed by Davis (1899), the models of slope development began to be widely discussed as may be further shown on Penck's hypothesis (Penck 1953). That, firstly misinterpreted by Davis as a "parallel slope retreat" (cf. Summerfield 1991) and then correctly presented in other modern works, was again titled "parallel slope retreat" in the otherwise excellent book "Soil geomorphology" by Daniels and Hammer (1992). The personality of King and his model (King 1953) came in a time, when geomorphology entered the period of the process-oriented approach using quantitative assessments. Many studies focused on local problems in seeking the heart of geomorphic processes, and the real conditions at study sites led scientists to consider the complex character of a landscape, including the interactions of fluvial system, soils, biotic environment and relief. The dynamics of geomorphological systems were analysed by Hack (1960) emerging in a concept of "dynamic equilibrium", the above mentioned interactions in landform evolution were interpreted by Ruhe et al. (1967) in their model of "backwearing"

ISSN 0016-7193 © Geografický ústav SAV / Institute of Geography SAS

and in the "nine-element model" designed by Conacher and Dalrymple (1977), drawing upon Milne's idea of "catena". The mathematical considerations on slope development have been done, for example, by Scheidegger (1961 and 2007), who has presented a number of equations representing different physical conditions of degradational slopes, or by Ahnert (1971), who mathematically expressed his comprehensive theoretical model (COSLOP) of slope evolution, in which the factors such as fluvial downcutting, weathering and downslope transport of material are being considered.

In spite of its limits, the process oriented approach helped to gain new and fundamental information about geomorphic systems and led to the formation of new disciplines, such as biogeomorphology, which draw upon the concepts of soil geomorphology, fluvial geomorphology, dendrology, landscape ecology, etc. The biogeomorphology was defined by Viles (1988) as "the concept of an approach to geomorphology which explicitly considers the role of organisms", or recently (Naylor et al. 2002) as "a science focusing on some aspects of the two-way linkages between ecological and geomorphological processes". Regarding the slope development, the biogeomorphological studies aimed especially at zoogeomorphic disruption of slopes (Volsamber and Veen 1985, Govers and Poesen 1998), or at problems of trees and their bioprotective effects (Stoffel 2005, Stoffel and Perret 2006, Raška 2007), possibilities of estimating the erosional rate using tree roots (Gärtner et al. 2001, Gärtner 2007) or trunks (e. g. Lehotský 1999), chronological assessments of mass movements, such as rockfall or debris flows (Stoffel and Perret 2006, Matyja 2007), biomechanical effects of trees in translocation processes in a surface layer, such as uprooting (Phillips and Marion 2006), etc. Besides these themes, as the biotic agents act in a diverse and dynamic manner, biogeomorphologists improved the idea of non-linear dynamics, which has been applied and conceptualized by Phillips (Phillips 1995 and 2007, Phillips and Marion 2006) as a concept of "perfect landscape". Regardless of all methodical improvements and widening theoretical background, there is a lack of studies testing the biogeomorphic effects in a non-linear development of slopes in different environments as well as complex biota-geomorphic interactions in one area (Naylor et al. 2002).

Therefore, the aim of this paper is to assess the biogeomorphic effect of standing and fallen trees (trunks) on the short-term evolution of rock-mantled slopes in a protected forest. Especially, we aimed at application of non-linear dynamics principle to concrete sites to evaluate, to what degree the slope development continual process and, how do different landscape factors and processes of a diverse time scale (weathering, soil development, vegetation) interact in slope development. Since the study sites are located in protected forest, the partial goal was then to evaluate the ability of trees (trunks) to protect the slope against sheet erosion or other disturbing factors.

METHODS AND MATERIAL

Study site

The research has been carried out at two selected sites of the Protected Landscape Area Czech Middle Mts., in valleys of Elbe river tributaries

(Czechia). In accordance with the main objectives, which were to determine the protective and erosive role of trees (trunks) in the development of slopes, we have selected the localities on rock-mantled slopes covered by trees (mostly alliance Fagion sylvaticae) of different ages (see Tab. 1). The localities are situated in a planar segment of slope (mid-slope) with an approximate inclination varying between 25° and 30°. In the so called Regional Plans of Forest Development (RPFD – OPRL), these localities belong to the forest type with slope-stabilization function. The general review on protected forests and their importance has been presented by Dorren et al. (2004) on the example of European Alps, concrete studies from that region have been done by Stoffel (2005) and others. In Central Europe, Matyja (2007) has focused on a local example of bioprotective effect on the North Slope of the Babia Gora Massif, important information may be derived from national forestry datasets, such as the National Forest Inventory in the Czech Republic (collective 2007).

Tab. 1. Characteristics of study sites

	Localization (WGS)	Altitude (m)	Slope angle	Exposure	Tree species	Stand structure richness	Age category (in years)
Průčelská rokle	N 50° 37´30´´ E 14° 5´46´´	480	28.3°	SW	European beech (*Fagus sylv.*)	simple	61-80 41-60 21-40
Sluneční stráň	N 50° 38´5´´ E 14° 3´55´´	330	25.0°	NNW	European beech (*Fagus sylv.*)	simple	61- 80 81-100 1- 21

Methods

The research at each site has been carried out in a square with the area of 100 m^2. In contrast to Phillips and Marion (2006), or collective (2007), who used circular study sites, we used the square because it enables us to assess all necessary attributes in relation to slope inclination (thanks to the concrete orientation of a square). The squares were divided into a regular network of 100 fields, giving 121 nodal points. For each of these points we have assessed its character (surface-cover mapping) according to the following categories: a) soil, b) clasts (as a result of downslope movement or uprooting), c) organic material (fallen leaves, vegetation, etc.) and d) tree (trunk). The points with soil coverage are considered the most exposed to erosion while the points with organic material or trunks represent the accumulation. Then, the distribution of standing and fallen trees (trunks) including their thickness measured in several transects and length has been mapped and the final map theme has been over-lain with the theme of surface-cover in the ESRI GIS environment. The combination of the previous two methods creates the information about spatial principles of exposition to protective (accumulative) and erosive processes.

The next step was to estimate the amount of material eroded (denuded) and accumulated thanks to trees (trunks). This has been done using the graphical-quantitative methods TER (total erosion rate) and TAR (total accumulation rate) devised by the authors (Fig. 1 and 2). Although there are already some methods especially for estimation of eroded material (cf. Gärtner 2007, Gärtner et al. 2001), these are usually based on sampling (cores, stems) and are therefore destructive and not applicable in protected landscape areas. Thus, we have based our method on graphical representation of different measured (non-destructive) parameters including slope inclination, size and position of trunks, position of roots etc. However, it has to be said, that these methods offer only partial solution and rather the estimation of accumulation and erosion rates than the exact results.

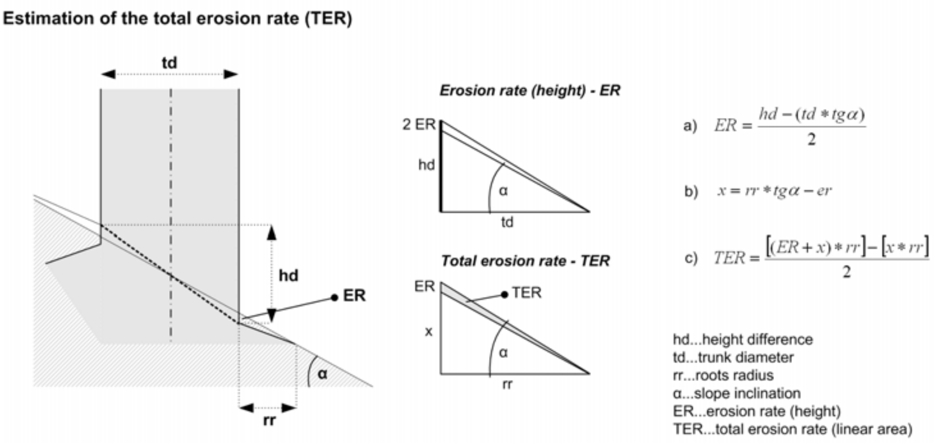

Fig. 1. The equation for estimation of eroded material

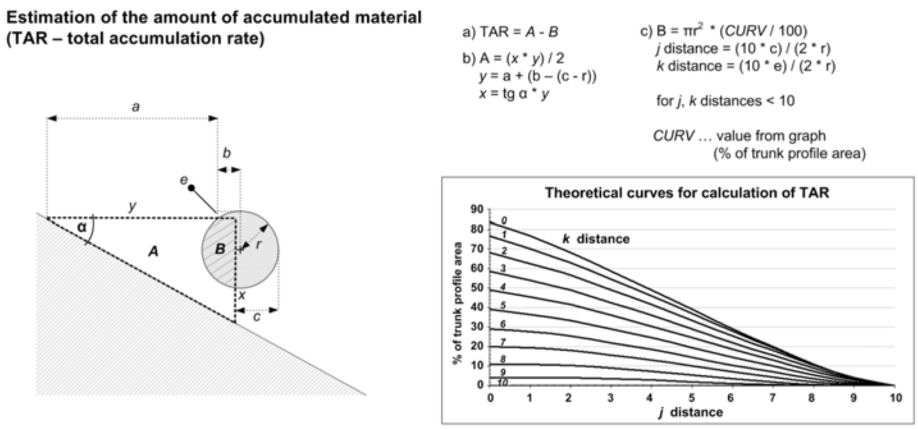

Fig. 2. The equation for estimation of accumulated material

The result values of TER and TAR for each standing and fallen tree (trunk) have been used to compute the approximate denudation and accumulation on whole study site and for one hectare. This has been done using the data for the parameters of standing trees and the length of fallen trunks, i.e. by multiplying the average TER with length of lying trunks and roots diameter of standing trees in the case of denudation and, by counting up the TAR values of all laying trunks (dam-like effects) in the case of accumulation.

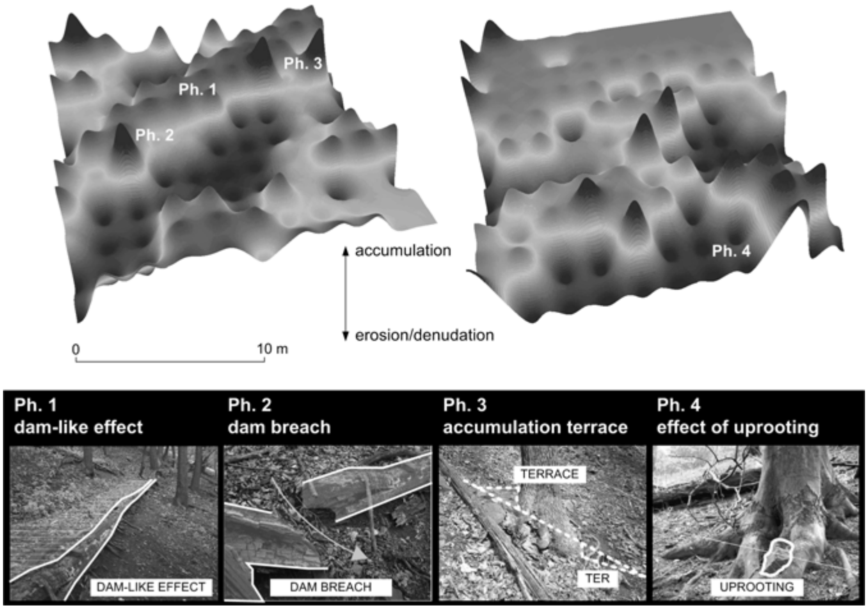

Fig. 3. Spatial models representing the balance between accumulation and erosion (denudation) at study sites

Below: examples of dendrogeomorphic effects at study sites

RESULTS

Surface coverage

The results of surface-cover mapping have been visualized as 3D digital models of terrain, where the altitudes symbolize the balance between accumulation (higher altitudes) and denudation (lower altitudes). Although there is a problem in transforming the discrete categories of surface cover into a model with a continuous surface, this method has shown a good potential for uncovering the principles of the spatial distribution of these categories. As regards the percentage of surface-cover categories (Fig. 4A), there is a dominance of soil and organic materials (litter) at both study sites. This result is in agreement with sharp boundaries in the spatial variations of these categories thanks to fallen trees (trunks) which influence the primary spatial matrix of surface-cover variations (see stock of timber in Fig. 4A). In contrast, the other categories (timber and rock clasts) represent rather the accidental component in overall surface-cover spatial variation.

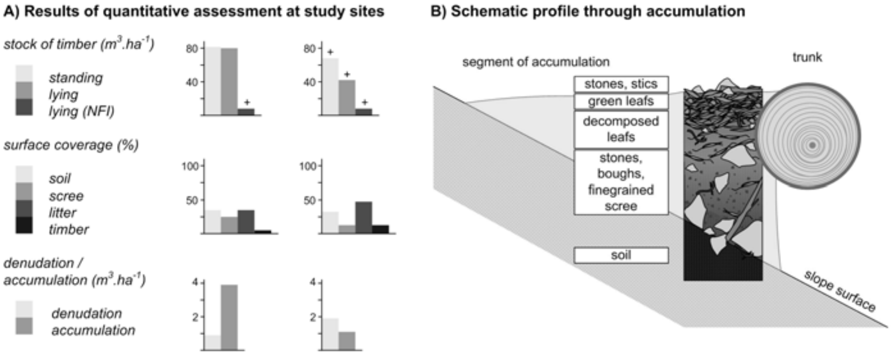

Fig. 4. A) The quantitative assessment of surface coverage and accumulation-erosion (denudation) balance at study sites

B) The profile through a typical dam-like accumulation

Source: National Forest Inventory of the Czech Republic (collective 2007).

Some differences in the spatial matrix of surface-cover are shown between the two study sites. Among these differences the absolute prevalence of litter at the second site (Sluneční stráň) should be mentioned. This prevalence, visible especially in the upper part of the model square, is due to lower slope angle and absence of tree stands near the mapped nodal points, which resulted in a mixed surface cover. Such nodal points of mixed character have been primarily mapped as a litter, whenever there was a presence of any organic material. This specific example shows one of the limitations of the surface-cover mapping, which is highly dependent on local conditions and the density of nodal points.

Rate of accumulation and denudation

The quantitative estimation of accumulation and denudation rates has been done using the TER and TAR equations designed by the authors. The TER computation is based on differences between the real slope inclination measured between two sides of a standing trunk and the average slope inclination of a model square. It shows relatively similar results at both study sites, which do not overreach the assumed values. These, when computed for a study site do not exceed 2 m^3. Nevertheless, the destructive methods of sampling and tree-ring analyses of roots would possibly make these results more accurate. That is to say that the TER equation as described in Fig. 1 also includes the parameter of radius of exposed root and as stated by Gärtner (2007), the exposed roots up to 1 m in length may be due not to erosion but to self-stabilization of the standing tree.

The rate of accumulation derived from the TAR equation has shown more surprising results. While derived from data about slope inclination, length of each accumulation and its height above the surface and parameters of its contact with laying trunk (dam-like effect; cf. Raška 2007), the quantitative assessment indicated dominance of accumulation at the first study site (Průčelská rokle) reaching 4 m^3. At the second study site (Sluneční stráň) it was only 1 m^3 which is however still comparable to the erosion (denudation) rate at the site.

Physical properties of accumulation dams

While trying to generalize some results of TAR and TER assessments it was necessary to understand the physical character of biogeomorphic effects at the study sites, that means firstly to accumulations caused by the dam-like effect. The heart of the problem was to analyse the temporal persistence of accumulation dams. This should indicate how long accumulations protect the surface against the disturbing factors. We used the combination of three methods, including the observation of the stage of decomposition in the case of fallen trees (trunks), analyses of the physical character of polypore species and profiles through the accumulation. Regarding the stage of decomposition, the number of cases of each stage type (according to collective 2007) at the studied localities was proportional, however the largest lying trunks were usually of the type "hard edge – centre soft" or "totally rotten". The analyses of polypore species have shown that some fallen trunks have had a stable position for at least one year or, have experienced only minimal rotation or sliding. Finally, the profiles through the selected largest accumulations (Fig. 4B) have indicated that the material is well compacted, partially interconnected with the underlying soil surface and tends to be sorted in layers (only the initial stages of such layers have been observed). This means, that these accumulations have longer persistence before the dam breach. Moreover, the plants on some of these large accumulations help in stabilization of a dam-like effect. On the other hand, small accumulations are usually not able to persist for such a long time, because they have smaller capacity and the wood is decomposed in a shorter time and thus the material has no chance to be stabilized.

DISCUSSION

The overall results may help to explain and refine our understanding of processes taking part in slope development. While the classic ideas assume the different processes typical of diverse slope segments (convex, mid-slope / planar, concave) based on field observations in concrete environments (Davis 1899, King 1953, Ruhe et al. 1967, Conachre and Dalrymple 1977, etc.) and application of physical laws (cf. Scheidegger 1961), it seems that the real situation on a short-term scale is rather more complex and variable. When seeking the proportion of denudation and accumulation at planar segment of slope (mid-slope), where the predominance of erosion and denudation usually been assumed, we have found the obvious variations and at one of the study sites also a prevalence of accumulation rate caused by the dam-like effect of fallen decomposed trees. Based on these analysies and measurements, we present the hypothesis of the "three-way development" in a mid-slope segment (see Fig. 5): a) accumulation beyond the trunk-dam – vegetation (especially herbs) – stabilization, b) breach of a trunk-dam – erosion – formation of a new trunk-dam, and c) breach of a trunk-dam – erosion.

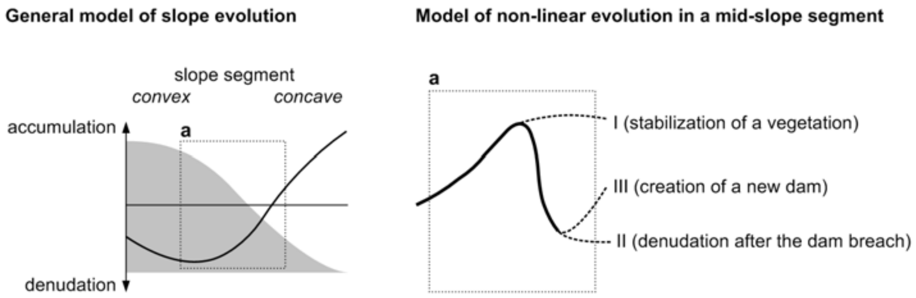

Fig. 5. Hypothetical model of a non-linear development of a mid-slope

The important point is, whether these strictly local examples may have more general validity in terms of time and space. Although the case study involves two large-scale locations, the observed distribution and density of standing and fallen trees (trunk) as well as some results of the National Forest Inventory (collective 2007) indicate, that the results are applicable for the broader territory of the protected forest of appropriate geomorphic conditions, climatic character and vegetational height scale. Moreover, the chronological assessment using polypore sp. and other proxy indicators such as stage of decomposition of trunks, or profiles through accumulation beyond the dam-like effect (Fig. 4B) have proved, that the biogeomorphic effects are related at least to the period of several years. Considering the diverse age of individual analysed cases and general rates of forest replacement (Phillips and Marion 2006), the biogeomorphic effect of trees may be one of the leading agents in slope development in a short-term perspective. Notwithstanding, such generalization will always be limited by our understanding of the problem of scale. As mentioned by Phillips (1995), there is the problem of disproportion between the time-scales of biotic communities (e.g. trees) and of landscape development resulting in the opinion that vegetation may be in fact a dependent variable rather than a controlling factor. Thus, the crucial issue seems to be finding the boundary between the time-scale where biota (vegetation) plays the leading role, and that where this relation is turned in favour of landform influencing the vegetation by the general conditions and disturbing processes.

CONCLUSIONS

The overall results of the study can be summarized in several points.

As already noted e.g. by Phillips (1995) in a theoretical context and tested by other authors (Stoffel 2005, Matyja 2007, Raška 2007) at concrete locations, vegetation may play a significant role in slope development especially thanks to its bioprotective and bioerosive effects. Consequently, the necessity of complex biogeomorphological studies at more single sites or areas (cf. Naylor et al. 2002, Stallins 2006) arises.

The methodical approach including the surface-cover mapping in combination with TAR and TER equations for estimation of the accumulation and erosion rates is applicable in protective forests on rock-mantled slopes and offers sufficient quantitative results. However, the accuracy of these results and comparison between different regions will always be influenced by differences in local conditions (rock type, distance of study site from erosion base and ridge, type of vegetation, etc.).

Despite its limits mentioned in the previous point, the study has provided good evidences of non-linear development on rock-mantled slopes, which was described in a "three-way concept" (Fig. 5).

The effectiveness of studied protective forests in reducing the sheet erosion and other disturbing factors is dependent especially on the presence of the dam-like effect, which is in accordance with recent trends in forest management suggesting the natural decomposition of fallen trunks in situ. Further, the results of surface-cover mapping have shown that there can be high variations between the stock of lying timber at concrete localities and that in the dataset of the National Forest Inventory, so the real protective effect may be much higher than formerly considered.

REFERENCES

AHNERT, F. (1971). *A general and comprehensive theoretical model of slope profile development. Final Report*. Washington-College Park (University of Maryland).

COLLECTIVE (2007). *National forest inventory in the Czech Republic 2001-2004: Introduction, methods, results*. Brandýs nad Labem (ÚHÚL).

CONACHRE, A. J., DALRYMPLE, J. B. (1977). The nine unit landsurface model: an approach to pedogeomorphic research. *Geoderma*, 18, 1-154.

DANIELS, R. B., HAMMER, R. D. (1992). *Soil geomorphology*. New York (Wiley).

DAVIS, W. M. (1899). The geographical cycle. *Geographical Journal*, 14, 481-504.

DORREN, L. K. A., BERGER, F., IMESON, A. C., MAIER, B., REY, F. (2004). Integrity, stability and management of protection forest in the European Alps. *Forest Ecology and Management*, 195, 165-176.

GÄRTNER, H. (2007). Tree roots – methodological review and new development in dating and quantifying erosive processes. *Geomorphology*, 86, 243-251.

GÄRTNER, H., SCHWEINGRUBER, F. H., DIKAU, R. (2001). Determination of erosion rates by analyzing structural changes in the growth pattern of exposed roots. *Dendrochronologia*, 19, 81-91.

GOVERS, G., POESEN, J. (1998). Field experiments on the transport of rock fragments by animal trampling on scree slopes. *Geomorphology*, 23, 193-203.

HACK, J. T. (1960). Interpretation of erosional topography in humid temperate regions. *American Journal of Science*, 258 A, 80-97.

KING, L. C. (1953). Canons of landscape evolution. *Bulletin of the Geological Society of America*, 64, 721-752.

LEHOTSKÝ, M. (1999). Soil erosion using Caesium-137 and dendrogeomorphic methods (case studies in Jablonka catchment). In Bielek, P., Briedlová, J., Jambor, P., eds. *Soil conservation in large-scale land use*. Bratislava (European Society for Soil Conservation, Soil Science and Conservation Research Institute), pp. 81-89.

MATYJA, M. (2007). The significance of trees and coarse woody debris in shaping the debris flow accumulation zone (north slope of the Babia Gora massif, Poland). *Geographia Polonica*, 80, 83-100.

NAYLOR, L. A., VILES, H. A., CARTER, N. E. A. (2002). Biogeomorphology revisited: looking towards the future. *Geomorphology*, 47, 3-14.

PENCK, W. (1953). *Morphological analyse of land forms*. London (MacMillan).

PHILLIPS, J. D. (1995). Biogeomorphology and landscape evolution: the problem of scale. *Geomorphology*, 13, 337-347.

PHILLIPS, J. D. (2007). The perfect landscape. *Geomorphology*, 84, 159-169.

PHILLIPS, J. D., MARION, D. A. (2006). Biomechanical effect of trees on soil and regolith: beyond treethrow. *Annals of the Association of American Geographers*, 96, 233-247.

RAŠKA, P. (2007). Comments on the recent dynamics of scree slopes in the Czech Middle Mountains. *Geomorphologia Slovaca et Bohemica*, 7, 43-49.

RUHE, R. V., DANIELS, R. B., CADY, J. G. (1967). Landscape evolution and soil formation in Southwestern Iowa. *Soil Conserv. Serv. Technical Bulletin*, 1349, 1-242.

SCHEIDEGGER, A. E. (1961). Mathematical models of slope development. *GSA Bulletin*, 72, 37-49.

SCHEIDEGGER, A. E. (2007). Some modifications of the slope development problem. *Geophysical Journal International*, 7, 40-53.

STALLINS, J. A. (2006). Geomorphology and ecology: unifying themes for complex systems in biogeomorphology. *Geomorphology*, 77, 207-216.

STOFFEL, M. (2005). *Spatio-temporal variations of rockfall activity into forest - results from tree-ring and tree analyses*. Ph.D. Thesis, Universität Freiburg, Freiburg.

STOFFEL, M., PERRET, S. (2006). Reconstructing past rockfall activity with tree rings: some methodological considerations. *Dendrochronologia*, 24, 1-15.

SUMMERFIELD, M. (1991). *Global geomorphology*. Harlow (Pearson).

VILES, H. A. (1988). *Biogeomorphology*. Oxford (Blackwell).

VOLSAMBER, B., VEEN, A. (1985). Digging by badgers and rabbits on some wooded slopes in Belgium. *Earth Surface Processes and Landforms*, 10, 79-82.

Pavel Raška, Tomáš Oršulák

BIOGEOMORFOLOGICKÝ EFEKT STROMOV NA KAMENISTÝCH SVAHOCH: HĽADANIE DYNAMICKEJ ROVNOVÁHY

Príspevok sa zameriava na hodnotenie biogeomorfologického vplyvu stromov, prípadne padnutých kmeňov, na vývoj strednej (planárnej) časti kamenistých svahov v pôdoochranných lesoch. S využitím biogeomorfologických metód sa na dvoch modelových lokalitách v Českom stredohorí vykonala kvantitatívna analýza objemu materiálu, ktorý sa akumuloval, prípadne denudoval vplyvom stromov (kmeňov). Oproti predpokladu vychádzajúcemu z väčšiny klasických koncepcií vývoja svahov, ktoré uvádzajú, že v strednej časti svahov výrazne prevažuje denudácia nad akumuláciou, uvedené výsledky ukazujú, že v krátkodobom horizonte niekoľkých rokov môžu bioprotektívne a bioerózne účinky drevín zapríčiniť podstatnú variabilitu v objeme erodovaného (denudovaného) a akumulovaného materiálu. Variabilitu možno najlepšie vystihnúť nelineárne konštruovaným modelom „vývoja tromi cestami“. Ten predpokladá nasledovnú trajektóriu vývoja: akumuláciu za kmeňovou hrádzou, prelomenie kmeňovej hrádze – erózia – vznik novej kmeňovej hrádze a prelomenie kmeňovej hrádze – erózia.