USING GEODETIC TECHNIQUES FOR GEOMORPHOLOGIC ANALYSES OF SCREE SLOPES IN LOW-ALTITUDE FORESTED REGIONS AND ITS IMPLICATION FOR CONSERVATION MANAGEMENT

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ABSTRACT:
Scree slopes (scree deposits) are landforms that may indicate palaeogeomorphic and palaeoenvironmental development of a landscape and often represent unique recent habitats for stenoecious species, thus increasing geodiversity ad biologic diversity of a landscape. The latter fact led to intense research and conservation of scree slope sites especially in mid-latitude environments. The conservation and management of scree slopes and their individual habitats are only possible while based on precise data about their topography. Moreover, if little information is available about the topography of scree slopes, the consideration on geomorphic and environmental change of them is far from convincing. In this study, we used the total station with a single beam scanning function to acquire the elevation data of a mid-latitude low-altitude scree slope in a forested site (Ceske stredohori Mts.). The total station was used as an effective alternative to airborne and terrestrial laser scanners. The design of filtration method including the computational procedures and evaluation of results from filtering process is presented. Finally, we evaluate the potential of the method to derive advanced geomorphologic characteristics of scree slopes for ecological applications, nature conservation and environmental management.

Keywords: *Scree slopes, geodiversity, conservation management, topography analyses.*

1. INTRODUCTION

Scree slopes (scree deposits) have been studied across different environments to clarify their role of palaeogeomorphic and palaeoenvironmental indicators (*Abrahams et al., 1994; Curry and Morris, 2004; Pawelec, 2006; Kirchner et al., 2007; French, 2007*), the specifics of their microclimatic regime including the presence of underlying permafrost (*Harris and Pedersen, 1998; Gude et al., 2003; Juliussen and Humlum, 2008*), and their biogeographical and ecological significance for stenoecious species (*Kubat 1974; Zacharda, 2000; Zacharda et al., 2005*). The range of methods that reveal additional information about properties of scree slopes is broad and comprises geophysical measurements (e.g. *Kneisel et al., 2001; Otto and Sass, 2006*), microclimatic measurements using dataloggers (*Zacharda et al. 2007*), or locating traps at the scree. However, there is persisting lack of precise input data related to topography of individual sites. That is due to the physical nature of scree slopes, on one hand, and to technical difficulties in data processing, on the other. The first reason is related to high inclination, internal heterogeneity and instability of scree slopes that are formed by clasts of varying size. Such

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clasts create high differences in altitudes at a micro-scale. Moreover, especially mid-latitude localities of scree slopes are often surrounded by high vegetation that is problematic for several methods such as remote sensing.

At the same time, the availability of precise data is a basic prerequisite for understanding topography-microclimate relation of scree slopes and for their effective conservation management. It enables to detect potential habitats of different species as well as processes that transform the scree slope. The precise data about topography can reveal the presence of habitat forming microclimatic regimes (*Schrott, 1999*), can help in preliminary organisation of field research (locating traps, temperature dataloggers, etc.) and optimise the environmental management of sites that are subject to environmental change.

The most advanced technology to acquire precise topographical data is airborne or terrestrial 3D laser scanning. It has been widely used in fluvial (*Heritage and Hetherington, 2006*) and aeolian geomorphology (*Nagihara et al., 2004*), or in a study of landslides and erosion (*Rowlands et al., 2003; Rosser et al., 2005; Armesto et al., 2009*). The scales of research also vary, from the local sites to extensive territories, where mostly the airborne variant of laser scanning is being used (e.g. *Kraus and Pfeifer, 1998*). The use of 3D scanner to detect the topography of scree slopes drives at several problems in some regions. Scree slopes in mid-latitude (e.g. this study) have a character of patches surrounded or partly covered by forest vegetation, and are often very steep. The existing algorithms that enable analyses of the air-borne scanned data at a level of individual trees (*Heurich, 2008*) are used where the land cover does not significantly change across the area. Screes on forested slopes, however, represent changing land cover pattern (forest and screes), which would raise the necessity to apply various filtering algorithms for different land cover classes. Moreover, the present-day algorithms for trees detection have higher efficiency in coniferous forests, which is not the case of many mid-latitude low-altitude scree slopes.

The use of terrestrial laser scanner is possible and may bring extent and detailed data. On the other hand, it has some limits if the precise location and orientation of measured data is necessary to enable connection of results with other datasets (GIS layers in a regional scale). In this case, the terrestrial laser scanner has to be supported with other geodetic equipment. The last problem that could be of high importance for institutions of nature conservation is the financial demand to carry out the extensive scanning procedure at many localities. For these reasons we used total station as an alternative to 3D laser scanning. The total station has been widely used for mapping and deformation analyses of landforms including the rock glaciers in mountain environment (e.g. *Kienast and Kaufmann, 2004*), but little information is available on its potential in low-altitude forested regions.

Based on the above mentioned recent lacks in acquisition of precise input data for scree slope studies, on one hand, and on the new opportunities given by modern field geodetic techniques, on the other hand, we set the major aim of the research, which was to design a protocol of terrestrial geodetic measurement of scree slopes to acquire the precise data for geomorphologic analyses and their implementation in conservation management of scree slopes.

The concrete aims of the study were (i) to design the method to measure and filter the topographical data at a level of elementary landforms and (ii) to summarise what other geomorphic and environmental characteristics may be derived from these data for use in ecological research, nature conservation and environmental management of scree slopes in generally. The topographical data were then used to evaluate the relation between elementary landforms and microclimatic regime, which is among the most important

factors influencing ecological significance and biological diversity of scree slopes. We assessed the potential of a total station with automatised single-beam scanning function to acquire the data for topography detection and analyses on a scree slope surrounded and partly covered by the European beech (*Fagus sylvatica*) dominated forest.

2. METHODS

2.1. Study site

The study site is located on a slope of the deep incised valley of Elbe river in the Ceske stredohori Mts. (Northern Czechia) (**Fig. 1**). The valley evolved in the neo-volcanic complex built by basaltic rocks (*Cajz, 2000*). The lithology together with high inclination of valley slopes allowed the evolution of numerous scree slopes. The scree slopes differ as regards their extent, genesis and age (e.g. *Cílek, 2000; Kirchner et al. 2007*), character of material (boulders, stones, gravel), general topography (altitude, aspect, inclination) as well as present landforms and processes that create conditions for various species.

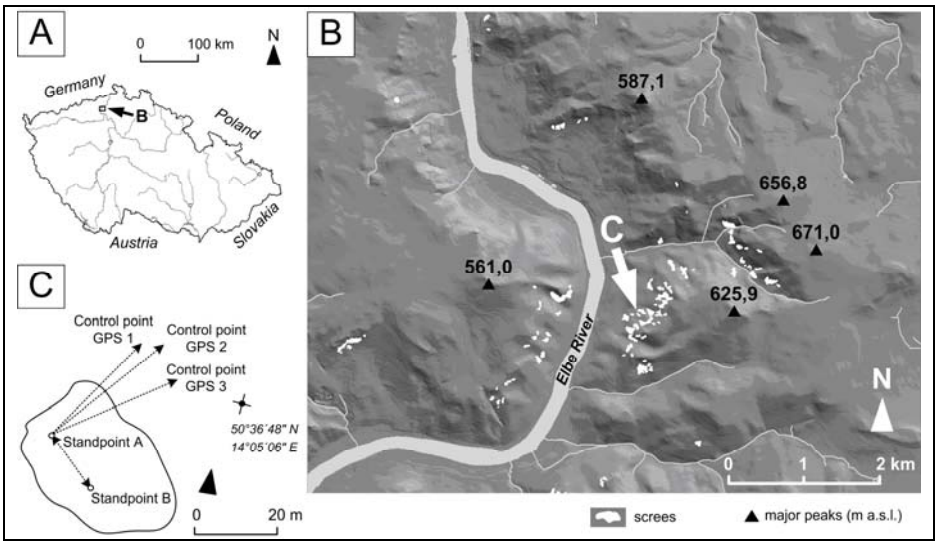

Fig. 1 (A, B) Location of the study site. (C) Location of control points, standpoints (position of total station) and measured area. (authors).

The study site itself is a westward oriented scree slope with inclination about 35° and dominance of clasts attaining 50 cm in their longest axis. The surrounding forests are represented by European beech (*Fagus sylvatica*) trees with an age mostly between 20 and 30 years (**Fig. 2**). The scree itself is covered with mosses, lichens and other dominantly chamaephytic and cryptophytic species. The site is one of approximately 30 localities of scree slopes in the region, which are typical of negative anomalies in microclimatic regime influencing biological significance of these scree slopes (*Kubát, 1971*). During the previous studies at the scree slope (*Raška et al., 2011*), we carried out the winter microclimatic measurement that confirmed the presence of scree circulation pattern influencing ecological diversity of the scree slope.

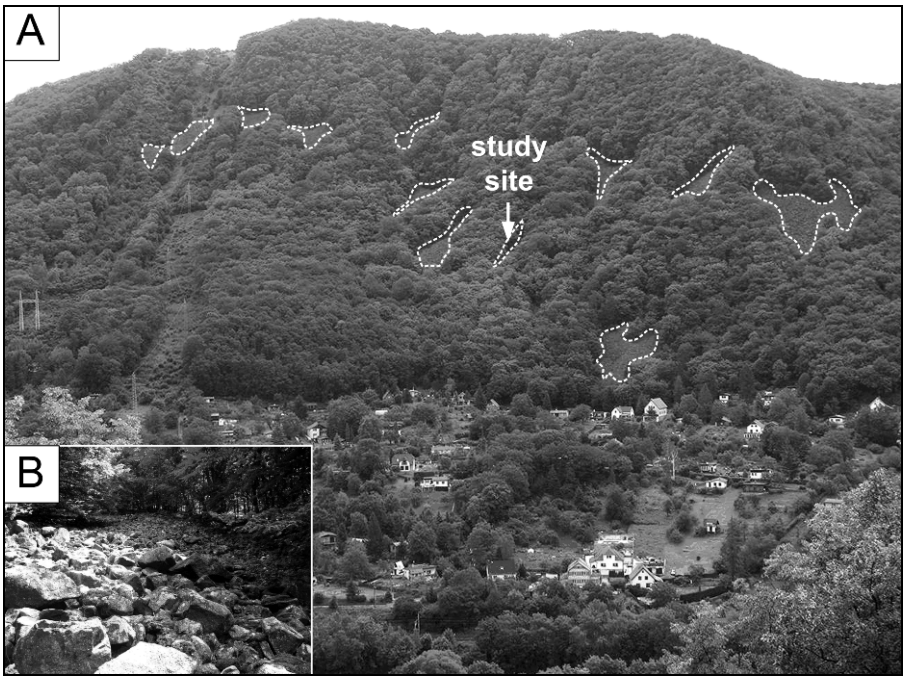

Fig. 2 (A) Oblique photo of the forested slope with the position of the study site.
(B) Scree deposits of the study site. (authors)

The overall characteristics of the detected winter thermal regime of the study site are summarized in the **Table 1**. During the winter, the warm air vent evolves at the upper part of the scree slope, limiting the persistence of snow cover. The site is subject to nature conservation in scope of the protected landscape area Ceske stredohori Mts., but - similarly to other localities in the region - encounters serious environmental stress (*Balej et al., 2008*).

Table 1. ***Basic statistical characteristics of temperature regime of the study site (T in [°C]).***

Site position	Average temperature	Average temperature (period of snow cover)	7-day running standard deviation	7-day running standard deviation (period of snow cover)
upper	7.80	7.46	0.88	0.58
lower	2.67	-0.40	1.52	1.25

2.2. Geodetic measurements

In this research, we applied the approach that is quite similar to static terrestrial 3D scanning, with a few differences: (i) total station instead of classic 3D Laser Scanner was used; (ii) GPS receiver with on-line connection with CZEPOS (national permanent reference station network) was used for referencing in national coordinate system (S-JTSK). We used the total station Trimble 5603 DR200+ that enables automatic measurement of selected area in prism-less distance measurement mode using Trimble Direct Reflex (DR) technology.

The process of measurement was divided into the following steps: (i) selection of standpoints (position of total station) and their referencing in national coordinate system in situ using GPS receiver Trimble R8 (see **Fig. 1C**) and real-time kinematic method (*Hofmann-Wellenhof et al., 2001*), (ii) automatic measurement of the scree slope, and (iii) filtration of off-terrain points that do not represent the real surface of the scree slope. The measurement was limited by dark rock surface with generally bad reflective properties and reflection angles (*Höglund and Large, 2006*).

When creating stochastic model of observations (for estimating absolute precision of every point), certain input information has to be taken into account. These were (i) precision of GPS positioning with use of real-time kinematic technique (*Hofmann-Wellenhof et al., 2001*), (ii) precision (and accuracy) of angle and distance measuring (*Trimble, 2001-2006*), and finally (iii) location of control points, standpoints and observed points. **Table 2** shows absolute precisions (in relation to national coordinate system S-JTSK and national height system Bpv) of the whole data set.

Table 2. ***Precision of observed data set.***

Coordinate component (S-JTSK, Bpv)	Minimal standard deviation σ [cm]	Maximal standard deviation σ [cm]
Y (east-west)	1.4	4.3
X (north-south)	2.0	5.5
H (height)	2.3	2.5

The use of Trimble "scan surface" procedure proved to be useful, as full automatisation of measuring cloud of points could be applied, which increases extent, speed and objectivity of scanning (e.g. *Armesto et al., 2009*). The crucial point during the measurement was to define the density of points measured. The basic criteria that influenced the density were the average size of clasts and diversity of elementary landforms. We assumed that the elementary landform has to be composed of at least three neighbouring boulders. As the average size of boulders at the site is 50 cm, the three neighbouring boulders represent the average variability of elevation on distance of 1 m. Therefore, the input minimum density of measured points was set to 1 point per square metre. In this way, the definition of density reflected the aim of the research, which was to obtain the topographical data at a level of elementary landforms and not a level of individual clasts.

2.3. Data filtering

During the measurement, 3D coordinates of 1175 points have been obtained from automatised prism-less measurement, 27 from manual measurement (supplementary points) and another 6 served as orientation points. Applied on an area of 806 m^2, the final density of points increased to 1.49 points per square metre. Increase in density is due to setting the tracking mode on the total station, which also causes the varying density of points in individual parts of the scree slope. Due to vegetation and possibly other minor factors (e.g. multiple reflection), the point cloud acquired from automatic measurement represented only the probable surface of the scree slope. Thus filtering process was applied. In the study described we computed approximation of surface as n-degree polynomial surface with robust method of adjustment computation (based on least square method). In basic principle, approximated surface can be described with the following equation:

$$h = c + \sum \left(a_i y^i_{S-JTSK} + b_i x^i_{S-JTSK} \right), \tag{1}$$

$$\text{for} \quad i = \left\{ \frac{1}{2}, 1, 2, 3 \right\}.$$

Where:

h = approximated height of terrain in national height system (Bpv),

y_{S-JTSK}, x_{S-JTSK} = horizontal coordinate in national coordinate system (S-JTSK),

c, a_i, b_i = coefficients that are products of filtering algorithm (see further text).

The degree of 0.5 in polynom (1) substitutes quadratic degree of z-coordinate in general equation of quadratic surface, while degree of 3 enables more dynamic changes in surface curvature and, at the same time, it does not leave the surface cuts as only-concave or only-convex. In case of the second degree polynomial, its second derivations would be always constant or equal zero. Coefficients a_i, b_i and c are products of filtering algorithm, where each observed point gets certain value of weight based on its distance to approximated surface. Initial surface has been computed with weights of all points equal to 1. Consecutively, these are the inputs to least square method. Afterward, the approximated surface is recomputed (with a new weight computation as well) as many times as the difference between the two following results exceeds the chosen threshold. Computation of weights (**Fig. 3**) was done in order that points with height above approximated surface in limits from 0 to height of height interval with maximum amount of points obtain weight equal to 1. Weight of points with height above approximated surface more than 90 % of all points (with sorted increasing heights) equals 0. Value of 90 % has been chosen so that it reflects input size of clasts and variance of height differences nearby ones. Generally, the higher is the diversity of landform, the higher should be this limit to minimize the probability that relevant point will be excluded during the filtering process. Weight of points in the middle interval is derived from the following equation:

$$p_i = \frac{1}{\left(1 + e_i + r\right)^2} + s \tag{2}$$

Where:

e_i = is height residual from least square method, and r and s have been chosen so that weight values at both ends of interval equal 1 and 0 (see **Fig. 2**).

Weight function is based on the one used in *Kraus and Pfeifer* (*1998*). The function reflects decreasing probability of point being on-terrain with its increasing height-above-surface. Contrarily to the original function, the one used in our filtering algorithm strictly comes through both threshold values (0 and 1). Robust adjustment has been performed as iteration process, where repeat-cycle stops when two following results differ less than preset value (based on required "robustness" of model). In our experiment 14 cycles have been performed before acquiring the final results. In each step of computing new weights, surface has been vertically shifted, so the surface comes through the point with the lowest height. Thus we obtain heights-above-surface in range from 0 to max (height) instead of normally distributed positive and negative residuals.

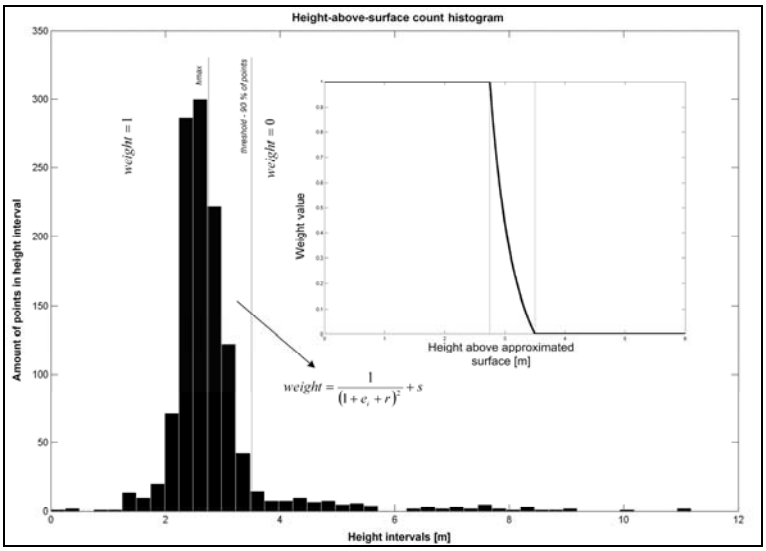

Fig. 3 Computation of weights in robust method. (authors).

Finally, points with height above critical value have been excluded from the dataset and filtered cloud of points has been created for further use. The final filtered cloud of 1096 points has been reevaluated manually according to preliminary geomorphologic research and 14 points were excluded based on nearest neighbour analyses.

3. RESULTS

3.1 Topography

The acquired dataset of 1082 filtered points represents the density of 1.34 points per square metre, which - regarding the slope inclination - enables to interpolate the contour theme with 1 m intervals. **Fig. 4A** shows the comparison of the most detailed contour national dataset accessible commercially and the contour theme derived from measurements presented in this study. The analyses of points, where the contours of these two dataset cross, show that the elevation differences between these datasets often reach 9 m, while the elevation range of the whole measured surface is 23 m. Moreover, significant differences in direction of contours and therefore in aspect of slope are apparent.

The result of filtration procedure was assessed by evaluation of the position of filtered off-terrain points within the scree slope. As it was supposed that the position of error points primarily reflect the vegetation pattern in the ecotone zone and the most differentiated parts of the scree slope, the analyses of error points´ position has been done in relation to the ecotone zone and significant landforms. The filtered points were located equally on forested and open (non-forested) part of the scree slope. The location of off-terrain points in the forested part is logical thanks to higher density of standing and fallen trees. The position in the open part of the scree slope is, however, more questionable. Therefore we measured the distance of these points from the edge that divide the open and continually forested part of the scree slope. Totally 39 % of these points were located up to 1 metre from the edge, 30 % between 1 and 2 metres, 18 % between 2 and 3 metres and only 14 % more than 3 metres from the edge (maximal distance was 3,9 m). These results, together with observed

presence of woody debris in the open part of the scree slope, confirm the assumed role of the ecotone zone on accuracy of the measurement. Only a small group of points located more than 3 metres from the edge seems to be caused by geomorphic diversity in the lower part of the scree slope, where rugged surface was created by moving boulders.

The contour theme created from measured points was used to compute the slope inclination and general curvature (horizontal and vertical curvature) of the scree slope and to detect present elementary landforms. While the slope inclination and curvature at a topographical level indicates the diversity of potential habitats, the elementary landforms reflects the habitat-related processes such as microclimatic regime (e.g. venting) and earth surface dynamics (rolling, sliding and bouncing of boulders or debris flows).

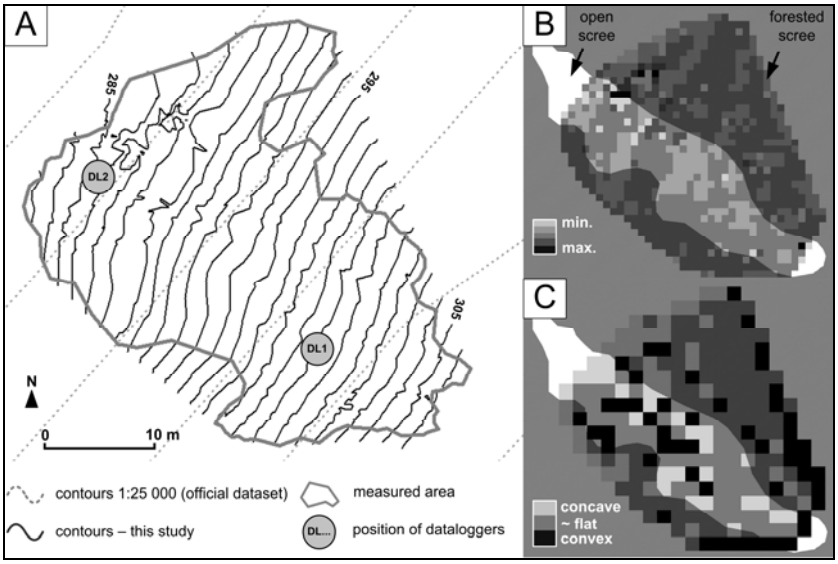

Fig. 4 (A) Density of commercial contours dataset and data from this study.
(B) Slope inclination derived from measured data (pixel size = 1 m).
(C) Overall curvature derived from measured data (pixel size = 2 m). (authors).

The slope inclination computed for pixel size of 1 m varies between 0° and 71.5°. The percentual representation of slope inclination intervals is 5.3 % (0° – 15°), 30.4 % (15.1° – 30°), 61.2 % (30.1° – 45°), 2.4 % (45.1° – 60°) and 0.7° (60.1° – 80°), which shows the predominance of steep slopes with inclination of more than 30°. The maximal values were achieved in the lower part of the scree slope. The graphical representation (**Fig. 4B**) shows the distribution of slope inclination intervals in stripes crossing the scree slope, which is most apparent in its lower part, where the old tourist path forms a "cut" into the slope profile. Smaller enclaves of lower inclination are located in the upper part of the scree slope and represent the upper surface of terminal lobes and other convex landforms.

The curvature was computed for pixel size of 2 m to include only the significant changes of surface geometry caused by adjoining elementary landforms and not by presence of large boulders. The curvature ranges from -35.9 (most concave) to 67.5 (most convex). The percentual representation of general curvature is 4.9 % (-70 – -30.1; very undulating), 20.1 % (-30 – -10.1; slightly undulating), 53.0 % (-10 – 10; almost flat), 17.7 % (10.1 – 30; slightly undulating) and 4.1% (30 – 70; very undulating). The highest values

of convexity were obtained for scree slope boundary in its upper part and for small parts inside the scree. The first case is caused by surface change from stony deposit to eroding soil cover, the latter is due to presence of partial accumulation of large boulders. This result may be supported with a fact, that convex surface inside the scree slope predominantly adjoins the most concave surface. This means that the more distinct the individual boulder accumulation is, the most distinct are its concave boundaries (i.e. transition to other landforms).

The elementary landforms derived from geodetic measurement, slope inclination and curvature analyses as well as geomorphologic mapping can be divided into two basic groups of concave and convex landforms (**Table 2**).

The **Table 3** also indicates the processes that take major part in the dynamics of these elementary landforms and their potential causes. The processes are primarily represented by the gravitational slope movements of boulders and finer scree, and by the "sieve effect" (*Carniel and Scheidegger, 1974*). The presence of boulders with a size up to 1 m in diameter is apparent from irregularities of contours in the central and lower part of the scree (see **Fig. 4A**). The finer scree is present mostly in lateral depression of the scree slope. The movement of scree and boulders is caused mostly by animal trampling (mouflons) and by climate-induced events (debris flows, frost coating of boulders).

Table 3. Elementary landforms of the study scree slope and examples of present geomorphic processes.

Geometry	Shape	Elementary landform	Landform dynamics
convex	linear	downslope ridges	rolling toward sides
		horizontal ridges	rolling from the front, sliding (animal trampling, frost coating)
		rampart above the path	rolling from the front, sliding (animal trampling, frost coating)
	non-linear	terminal lobe	slow sliding (animal trampling, frost coating)
		boulder accumulations	rolling (impacts of other boulders)
concave	linear	tourist path	wobbling of stones (human walk, animal trampling)
		lateral downslope depression	rolling, debris flows (animal trampling, effect of woody debris, climate-induced events)
	non-linear	hole	filling by surface and subsurface movement of finer scree

4. DISCUSSION: APPLICATIONS TO ECOLOGY AND ENVIRONMENTAL MANAGEMENT

Several studies pointed out that scree slopes (scree deposits) represent suitable habitat for stenoecious species because of their microclimatic regime (if developed), topographical diversity and character of clast surface. The thermal regime with low winter oscillation of temperature in the upper part of the scree and low spring-to-summer oscillation in the lower part of the scree (presence of ice holes and cavities) favours cryophilic species (e.g. *Kubat 1974; Zacharda 2000*). The topographical diversity is caused by presence of large boulders which predispose the variability of slope inclination and orientation of surface at a microtopographical level (see **Fig. 5A**). The effects of surface properties relate to the

presence of exposed rock that is sensitive to changes in temperature, improves ground-air thermal coupling, and allows the run-off to concentrate on clasts. The surface geometric properties may also be important for microclimatic and topoclimatic modeling (*Kang et al. 2000; Keryn et al. 2004*). At the same time, the resistance of rock creates stable environment in comparison to soily and gravely surface that is being affected by erosion. All the above mentioned factors reflect the fact that the geomorphic character of screes significantly influences their ecological and environmental properties.

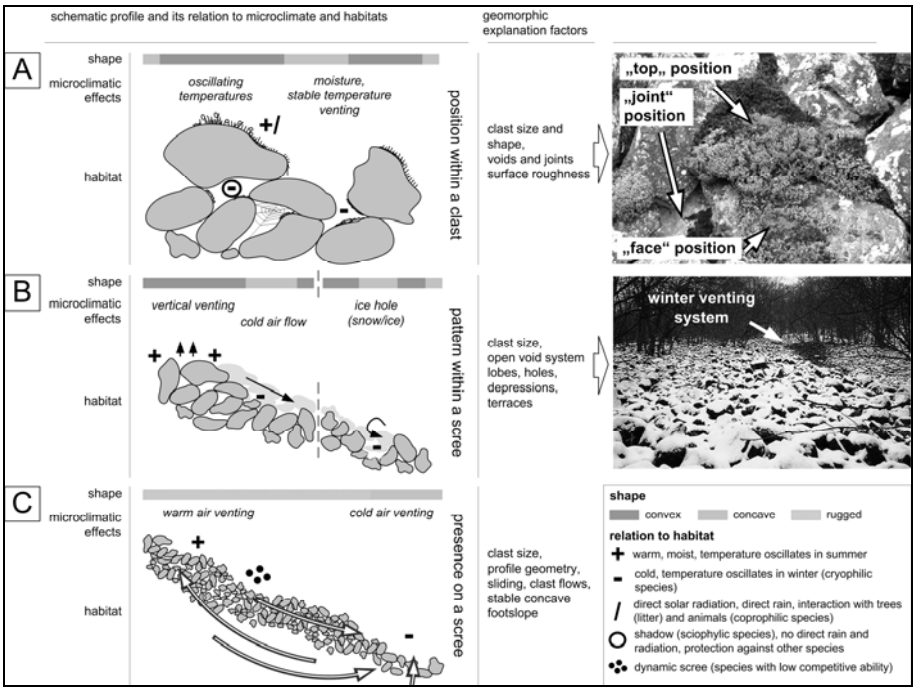

Fig. 5 Ecological effects of topography and microtopography at the level of individual clasts (A), of elementary landforms (B) and of a scree slope (C). (compiled from authors research and from *Kubat 1974; Lüth 1999; Bohn and Lohmeyer, 1999; Kubesova 2000; Zacharda et al. 2007*)

4.1. The relation of elementary landforms to ecological diversity of the site

In this case study, we focused on a level of elementary landforms that – thanks to the data density – also enables the evaluation for a scale of the whole scree slope (**Fig. 5**). The method described in this study enables to specify several of the above mentioned properties. The point cloud and its analyses in GIS, which served to derive the topographical characteristics of the site, were used to distinguish the elementary landforms of the scree slope. These landforms are created and transformed by variable processes and contribute differently to the microclimatic regime. The non-linear depressions in the lower part of screes usually enable the persistence of snow and ice to warm months, however, no such ice holes were detected at our study site. On the other hand, the study site is characteristic with linear depressions located in the upper part of the slope that are suitable for surface and near-surface air flow. A limited capacity of the warmer air, which can not

exhalate from the front of convex landforms, exhalates from their concave sides and flows to these linear depressions.

The convex downslope oriented landforms with terminal lobes are suitable for storage and venting of air with stable temperature. The presence (e.g. terminal lobes) and absence (e.g. ice holes) of certain elementary landforms together with the results of microclimatic measurements indicate that the scree circulation regime in the studied scree is well developed only in its upper part and corresponds with a microclimatic mode of warm-cold air exchange with a minimal contribution of chimney effect (*Kubat, 1971*). The representation of geometric properties of the study site (inclination and curvature) summarised in the section 3.1 shows quite high variability of surface that can be suitable for both sciophylic species and species preferring direct sun radiation.

The geomorphic processes that transform the elementary landforms limit or favours different species. The most landforms are composed of large boulders that create microclimate-conditioned habitats for cryophylic species. On the contrary, there is apparent dynamics of finer scree in downslope depressions in the study site (e.g. debris flows) that favour species with lower competitiveness, which could not colonise habitats with stable large boulders (see **Fig. 5C**). In generally, the analyses of type and rate of all processes involved may be crucial to evaluate the stability of habitats or the scree ecosystem.

4.2. Implications of the method for conservation management

The overall ecological pre-assessment of the study site based on analyses of its topography emphasizes the following points that should be reflected in the conservation and environmental management of the site: (a) the evolution of scree microclimatic regime is limited, while being allowed by diversity of convex and concave elementary landforms in the upper part and limited by absence of concave footslope, (b) the inclination and curvature creates diversity of habitats with different incoming solar radiation, the void system between large boulders favours cryptophilic species, (c) the dynamics of the study site includes mostly rolling and debris flows (in downslope depressions). The rolling is often caused mostly by moufflon hordes and disturbs old localities of endangered species. The potential damage is represented by widening ecotone zone and bioerosive effects of woody debris in the landforms built by finer scree. The movement of finer scree in downslope depressions may conclude in accelerating sieve effect that could fill the open void system and transform the microclimatic regime of the site. As the climate-induced processes are hard to manage, the attention should be paid mostly to limit the movement of moufflons and to decrease the volume of large woody debris at the site.

5. CONCLUSIONS

In this paper, we suggested the methodical procedure for field measurement of scree slope topography at a level of elementary landforms using the total station, and for subsequent mathematical filtering of obtained data for the use in ecological applications (field research and monitoring), nature conservation and environmental management. The aim of the research was to set out the methodical procedure to acquire precise topographical data for the research of scree slope microclimatic regime, habitat diversity, and management. The total station was used because of its suitability for hard forested terrain and good accessibility for institutions of nature conservation. The designed procedure including filtering algorithm may also be used for 3D scanners with minor adjustments or for high-precise microtopography measurement by means of total station (in this case the

time of measurement significantly increases). The obtained data were used for geomorphometric analyses and for detection of elementary landforms. For the purpose of further studies of scree slopes, we set the following protocol of geodetic measurement to obtain precise topographical data:

(i) equipment selection and evaluation of its accuracy;

(ii) preliminary geomorphologic research and selection of standpoints;

(iii) setting the point cloud density according to average clast size at the site;

(iv) automatic measurement supported with manual measurement of reference points;

(v) filtration of off-terrain points - setting the weight function, robust adjustment, manual reevaluation based on nearest neighbor analyses;

(vi) GIS processing - selection of adequate interpolation method, geomorphometric analyses.

The geomorphic properties of the scree slope were supplemented with the results of previous microclimatic measurement in the study site. The microclimatic data enabled to evaluate the relation of topography and microclimatic regimes that are one of the most deterministic factors for ecological significance of scree slopes and their habitat diversity.

Finally, we proposed the basic instructions for environmental management of the site. The information that can be obtained or derived from the proposed methodical procedure are:

(i) identification of elementary landforms and dominant geomorphic processes;

(ii) finding the elementary landforms that precondition the microclimatic regime of the scree slope - especially linear depressions and terminal lobes, deriving scree slope profile;

(iii) topographical factors of habitat diversity (exposed and shadowed habitats, stable and dynamic habitats);

(iv) stability analyses of different parts of the scree slopes to assess the relative speed of environmental transformation of the scree slope;

(v) measures of conservation and environmental management of the scree slopes.

The designed procedure enables to assess the diversity of potential and real habitats within the scree and to evaluate their potential change due to geomorphic processes. This, in turn, helps to point out the major aims for environmental management of the sites.

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