Carpathian Journal of Earth and Environmental Sciences, February 2016, Vol. 11, No. 1, p. 27 - 36

ASSESSING THE ANTHROPOGENIC IMPACT ON GEOMORPHIC PROCESSES USING TREE-RINGS: A CASE STUDY IN THE FĂGĂRAȘ MOUNTAINS (ROMANIAN CARPATHIANS)

Patrick CHIROIU, Adrian C. ARDELEAN, Alexandru ONACA, Mircea VOICULESCU & Florina ARDELEAN

West University of Timişoara, Department of Geography, Bdul Vasile Pârvan, 4, 300223-Timişoara, ROMANIA
p.chiroiu@gmail.com, adrian.ardelean86@e-uvt.ro, ducuonaca@yahoo.com, voicu@cbg.uvt.ro, florina.ardelean@cbg.uvt.ro

Abstract: In mountain environments, geomorphic slope processes such as rockfall, debris-flows and snow avalanches are common and widespread, their natural occurrence being controlled by topographic, geological and climatic parameters. Instead, in regions where human activities are present, the slope equilibrium and the natural dynamics of geomorphic processes can be significantly altered. For instance, the construction of the alpine Transfăgărășan Highway, which crosses the Făgăraș Mountains in the Romanian Carpathians, affected the morphogenetic potential of the Bâlea and Capra valleys, influencing slope stability and present-day geomorphic process dynamics. Anthropogenic disturbance may induce cascading environmental changes, posing a growing threat to human lives and activities, thus urging for the initiation of logical research approaches in this direction. Dendrogeomorphology has been used since the 1970s in the study of slope processes, becoming a well established reconstruction and analysis method. In our study, we employed tree-ring based techniques to examine the anthropogenic impact on geomorphic processes on a scree slope located right beneath the runway of the Transfăgărășan road. A total number of 33 *Picea abies* trees were sampled in the lower part of the scree to reconstruct the rockfall and snow avalanches activity by the analysis of geomorphic-induced growth disturbances in tree-rings. Another 20 *Picea abies* trees were selected from an undisturbed stand located north of the investigated area to build a reference chronology. The relative ages of the two stands were then compared to evaluate the impact of human activities in natural forest and landscape dynamics. The results of our study indicate that the investigated scree was initiated by the time of road construction activities in the early 1970s and is nowadays shaped by various geomorphic slope processes. Rockfall rates are most probably amplified by road traffic, whereas snow avalanches seem to follow a natural regime in the cold season, when the alpine road is closed.

Keywords: tree-rings, human impact, dendrogeomorphology, slope processes, snow avalanches, Transfăgărășan, Southern Carpathians.

1. INTRODUCTION

Slope processes are natural-driven geomorphic phenomena which occur whenever the shear strength is exceeded by the gravitational forces, inducing slope instability (Varnes, 1978). Specific topo-climatic factors and surface characteristics prepare and control the manifestation of such processes, whereas the actual triggering is caused by the surpassing of slope stability thresholds (McClung & Schaerer, 2006). In mountain environments, natural-driven slope processes such as rockfall, debris-flows or snow avalanches are common and widespread (Janke & Price, 2013).

Along with natural triggers - i.e. extreme values of meteorological parameters, earthquakes, etc. - human activities can as well enable slope processes (Gregory & Walling, 1987). In some cases, the anthropogenic contribution is minimum, being limited to the triggering of a single event (e.g. the release of a snow avalanche; Voiculescu, 2014), whereas in other cases, the human influence expands upon creating prerequisites for the initiation and development of these phenomena, in areas where they never occurred before (Loczy & Sütö, 2011). Studies have been carried out in the past to analyze the magnitude and frequency of man-induced geomorphic processes (Thomas, 1956; Turner et al., 1990). Currently, increased focus has been set upon the study of these external disturbances (Slaymaker et al., 2009; Syvitski & Kettner, 2011; Bruschi et al., 2011), mainly because the geomorphic impact of human activities - such as agriculture, mining, transportation or tourism - is growing exponentially and as a consequence, the dynamic equilibrium of affected natural systems is dramatically changed (Goudie, 2005). Anthropogenic geomorphology (Szabo et al., 2010) points on the primary role the „human agent" has gained in initiating, increasing, weakening or inhibiting geomorphic processes. The amplitude of erosion, sediment transport and storage are significantly accelerated in regions with intense human activities (Bruschi et al., 2013). Moreover, anthropogenic disturbance may induce cascading environmental changes, posing a growing threat to human lives and activities, thus urging for the initiation of logical research approaches in this direction (Szabo, 2010).

Natural-driven slope processes which interact with forested areas have been repeatedly studied by means of dendrogeomorphology (Alestalo, 1971; Butler & Malanson, 1985; Stoffel et al., 2005; Stoffel & Perret, 2006; Szymczak et al., 2010; Lopez-Saez et al., 2011; Corona et al., 2010, 2012). The analysis of anomalous tree-ring growth induced by geomorphic disturbance is a well established method (Shroder, 1978, Shroder Jr. 1980; Stoffel & Bollschweiler, 2008; Stoffel et al., 2013), which allows long-term reconstructions of past events, as well as assessments regarding frequency, magnitude, and spatial spread of various slope processes (Stoffel & Bollschweiler, 2009). Subsequently, human activities are active exogenous factors which exert a broad range of influences on tree growth (Rolland et al., 1998; Motta & Nola, 2001; Wick et al., 2003; Juknys et al., 2014). In this sense, in Romania, dendrogeomorphology has been used to investigate the effects of mining activities on sediment transfers and tree growth (Pop et al., 2014).

It is therefore the aim of this study to examine the geomorphic activity and to assess the anthropogenic origin of a scree slope located beneath an alpine highway which crosses the Făgăraș Mountains (Romanian Carpathians) by employing a tree-ring based approach.

2. STUDY AREA

The present study was conducted on a scree slope (45˚37' 59" N, 24˚36' 37"E) located in the Bâlea Valley - Făgăraș Mountains, Southern Carpathians. The investigated area lies just beneath the runway of the Transfăgărășan Highway (see Fig.1), extending over 22.000 m² and ranging from 1315 to 1535 m.asl. The mean slope angle is 35.5˚ with a minimum value of 24˚ near the valley floor and gradually increasing angles to a maximum of 47˚ in the upper part. The geological setting consists of easily weathered foliated crystalline schists such as phillites and micaschists, with gneisses and amphibolitic schist layers (Urdea, 2000).

Along with rockfall and snow avalanches, gullying and torrential erosion are active morphogenetic processes in the area (Urdea, 2000). In the upper part of the scree slope, just beneath the highway, a narrow gully separates two steep cliffs and runs downwards, penetrating the forested area found in the lower part of the slope, at 1350 m asl. The steep walls located above and beneath the road serve as source areas for rockfall. Falling, bouncing and rolling rock fragments are deposited along the slope in characteristic patterns (e.g., levees, isolated boulders, small talus cones). The mantle of debris consists of pebbles, cobbles and boulders with sizes considerably growing as we descent towards the valley floor, where the largest fragments can be found. The steep slope and the existence of an avalanche track above the runway of the Transfăgărășan road, together with a consistent snow cover during the cold season (Voiculescu et al., 2011) stand for the occurrence of snow-avalanches in the area.

The construction of the alpine Transfăgărășan Highway which lasted between 1970 and 1974 involved the dislocation of 3.8 million tons of rocks (Urdea et al., 2009) and the employment of 6250 tons of dynamite (Petrescu, 2014). This massive human intervention clearly influenced the morphogenetic potential of the valley. Road building and excavation operations reduced the slope stability increasing gully erosion and rockfall and stimulating present-day geomorphic process dynamics (Urdea, 2000).

The upper part of the scree slope is free of vegetation, while the lower half is colonized by a spruce forest (*Picea abies* (L.) Karst.). Pioneer tree species with flexible stems, such as alder (*Alnus viridis*) are mainly found on the margins of the gully which penetrates the spruce forest. The majority of trees show clear evidence of geomorphic disturbance, such as impact scars on the upslope side of the stem (Trappmann & Stoffel, 2013), tilted and *J*-shape trunks (Casteller et al., 2011). On the other hand, apparently older and undisturbed trees grow laterally towards north and above the road.

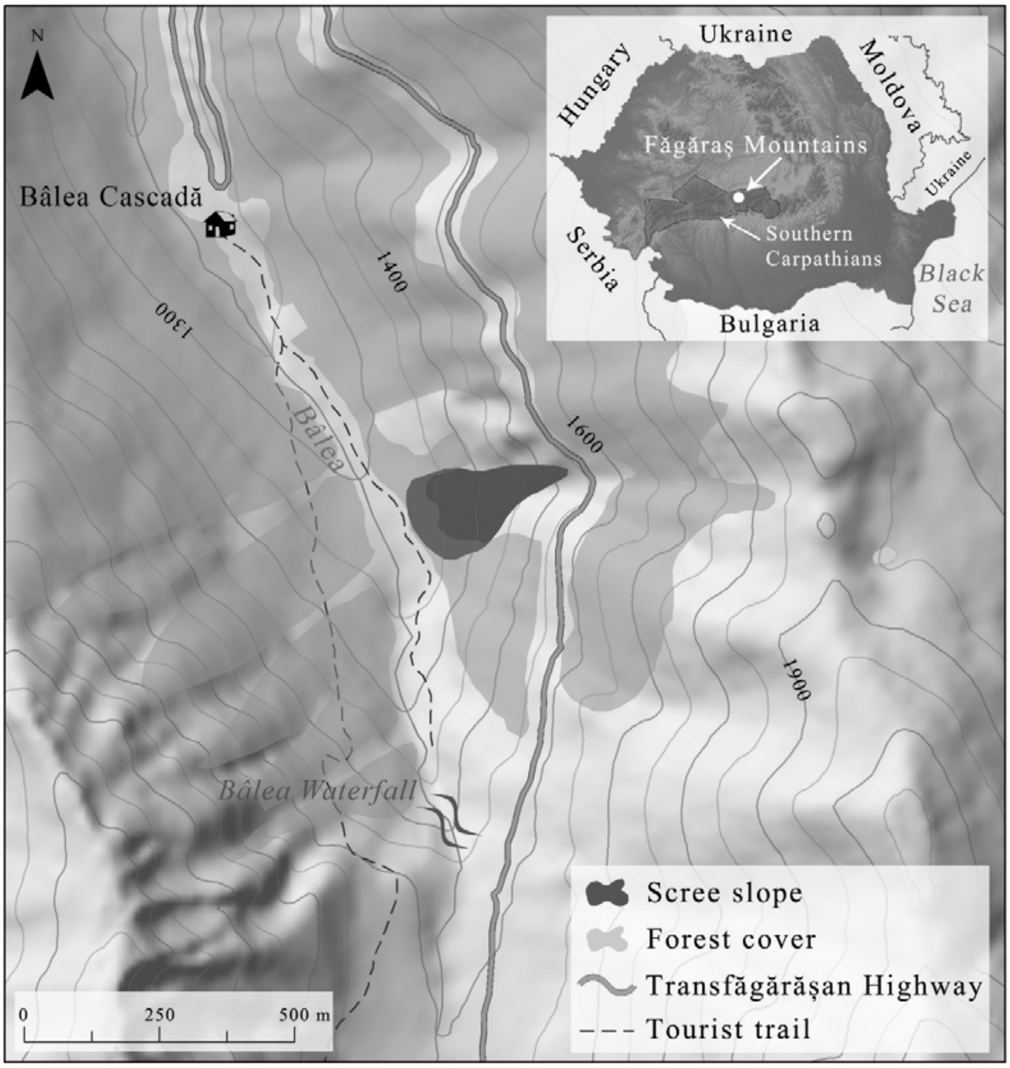

Figure 1. Location of the study area in the Bâlea Valley - Făgăraş Mountains.

According to the climatic data recorded at the nearby Bâlea meteorological station (45º36’17’’N, 24º37’01’’E, 2038 m asl, period 1979-2007), mean annual temperature is 0.4°C and the mean annual precipitation is 1220 mm year^{-1}. The average number of days with snow cover is 221. Even if snowfall is possible during the whole year, significant amounts of snow, a prerequisite for snow avalanche occurrence, appear mainly between January and April (Voiculescu et al., 2011).

3. METHODOLOGY

3.1. Field techniques

Firstly, a geomorphologic evaluation of the investigated area served for the assessment of prevailing geomorphic processes associated with the morphology occurring in this site. The contour of the scree slope was delineated using a Trimble GeoExplorer 6300DGPS.

A total of 33 *P. abies* trees were selected from the lower part of the scree (Fig. 2) in order to identify evidence of past geomorphic disturbance. The sampling strategy was focused on trees with visible anomalies in tree morphology, such as bent stems, impact scars and broken trunks with candelabra growth (Stoffel & Bollschweiler, 2009). The reconstruction is based on information contained in 96 increment cores, extracted with Haglöf increment borers (ø 5.15 mm, length max. 40 cm). The curved trees were sampled at the maximum bending angle (Corona et al., 2012), by taking two cores from bark to bark, one in the tilting direction and the other one perpendicular to the first. A minimum of three cores were extracted in the case of injured trees, from the overgrowing scar tissue (Stoffel & Bollschweiler, 2008). For each disturbed tree, an additional core was extracted at the lowest possible point to minimize errors in tree-age calculations.

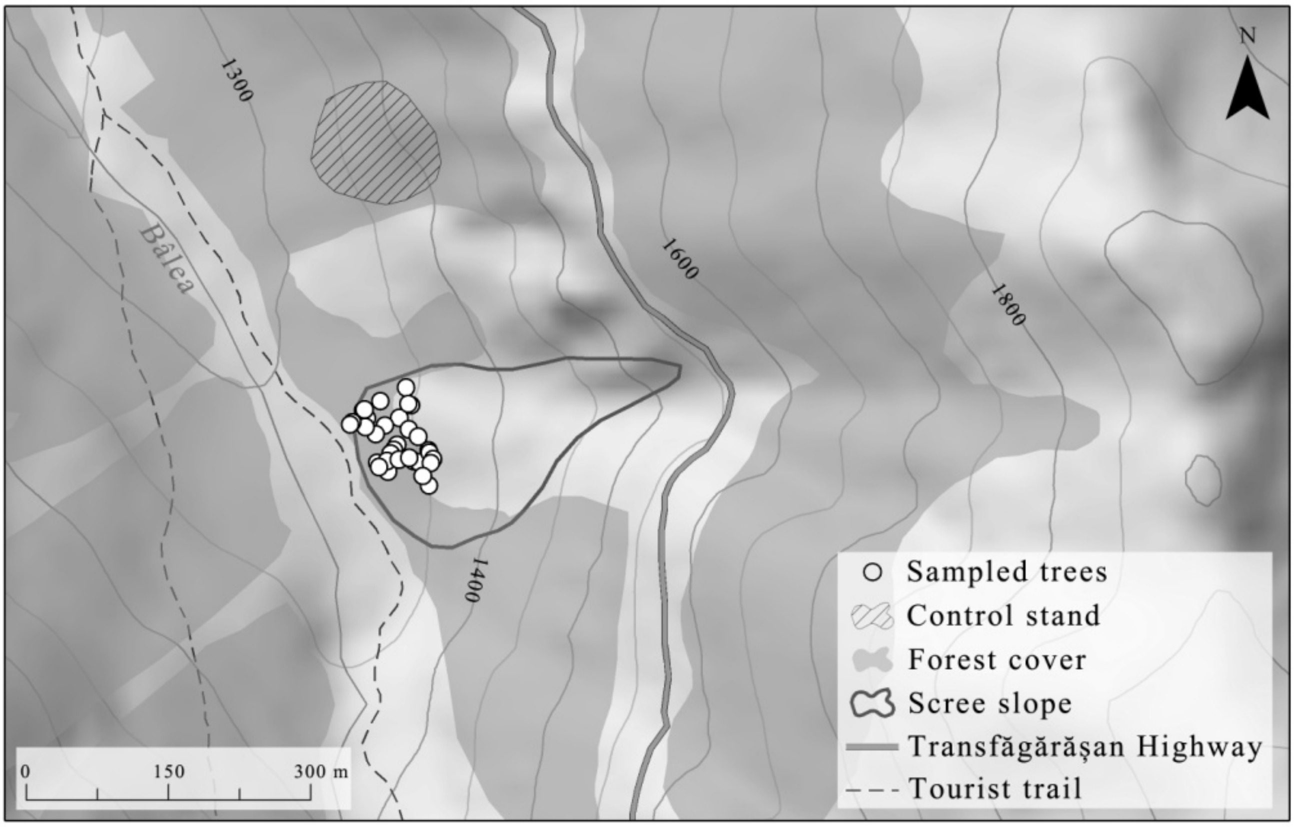

Figure 2. Location of the two investigated forest stands. Geomorphological disturbed trees were sampled in the lower part of the scree slope, while undisturbed trees were selected from the control stand located north of the scree.

Another 20 undisturbed trees were sampled from a site located 100 m to the north of the study area, referred hereafter as the control stand (Fig. 2), in order to build a reference chronology and to assess stand age differences between the sites.

Additional data was collected for each tree as follows: diameter at sampling height, description of the disturbance, sample heights, spatial coordinates and photograph of the sampled tree with emphasis on anomalous growth features.

3.2. Sample analysis and interpretation

Standard dendrochronological procedures were applied to prepare the samples (Bräker, 2002). Tree-rings were counted and measured using a LINTAB 5 measuring system connected to a Leica stereomicroscope and TSAP-Win Professional 4.64 (Rinn, 2013). After visually and assisted crossdating, the procedure was verified using COFECHA (Holmes, 1983), and a tree-ring width reference curve was obtained for the control stand.

Dendrogeomorphic dating of past events is based on the identification and dating of internal anatomical reactions (Stoffel & Corona, 2014), so called growth disturbances (GD): onset of reaction wood (Timell, 1986), eccentric growth (Braam et al., 1987), abrupt growth suppression and release (Burrows & Burrows, 1976), formation of callus tissue (Stoffel & Bollschweiler, 2009), and the formation of tangential rows of traumatic resin ducts Stoffel, 2008). In our approach we only used as clear indicators of geomorphic disturbance, reaction wood doubled by eccentric growth, the formation of callus tissue and tangential rows of traumatic resin ducts (TRD). Abrupt growth changes were disregarded due to the youth of the trees. Moreover, because young trees are highly sensitive to the influence of several factors - i.e. strong winds, snow pressure - besides geomorphic processes (Germain et al., 2009), the ten innermost rings were excluded from the analysis.

In order to identify widespread events that affected a high number of trees we calculated a semi-quantitative index I_t (Shroder, 1978, Reardon et al., 2008, Germain et al., 2009, Casteller et al., 2011, Voiculescu & Onaca, 2013, 2014) based on the formula:

$$I_t = \left(\left(\sum_{i=1}^{n} Rt \right) / \left(\sum_{i=1}^{n} At \right) \right) \cdot 100 \quad (1)$$

where *Rt* = responding trees in year *t*; and *At* = sampled trees alive in year *t*.

4. RESULTS

4.1. Age structure of the stand

Based on the pith age at sampling height, the average age of the *P. abies* trees located on the scree slope was estimated to 17 years. In May 2011, the month of the sample campaign, the oldest tree analyzed here formed no more than 30 increment rings, while the youngest attained sampling height in 2005. Age distribution of the sampled trees points to a colonization trend, older trees being exclusively located towards the lower limits of the slope, whereas trees sampled on the upper parts of the scree showed to be younger (Fig. 3). On the other hand, all reference trees sampled in the control stand exhibited ages between 78 and 121 years.

4.2. Growth disturbances and event years

Analyses of the sampled cores extracted from trees colonizing the lower part of the scree slope allowed for identification of 41 GD induced by geomorphic processes. The formation of reaction wood caused by tree tilting appeared 21 times, while TRD and callus tissue - responses to wood injury - were found in 20 cases (15-TRD, 5-CT).

The histogram depicting the temporal distribution of the various types of GD is shown in Fig.4. The first reactions to slope-process-induced disturbances have been dated to 1995 and afterwards almost every year showed evidence of geomorphic activity on the investigated scree slope. Calculation of the I_t index shows an increased dendrogeomorphic signal in 2005 with a maximum value of 46.9%, pointing to a widespread event that affected almost half of the sampled trees (see Fig.5).

5. DISCUSSION

The present paper employs tree-ring techniques to determine geomorphic process activity on a scree slope located in the Bâlea Valley (Făgăraș Mountains, Romania) and at the same time, uses relative ages of two neighboring forest stands to point out the anthropogenic origin of the study area.

The samples collected from 33 *P.abies* trees colonizing the lower part of the scree confirm the manifestation of slope processes by displaying typical anatomical responses to geomorphic disturbance. Starting from 1995, GD were identified and dated for almost every year, proving that the investigated scree slope is currently geomorphological active. Geomorphologic observations on the study site led to the assumption that rockfall and snow avalanches could be considered as the main active slope processes shaping the scree. The strong dendrogeomorphic signal for 2005 indicates a large-scale event, most probably a high-magnitude snow avalanche.

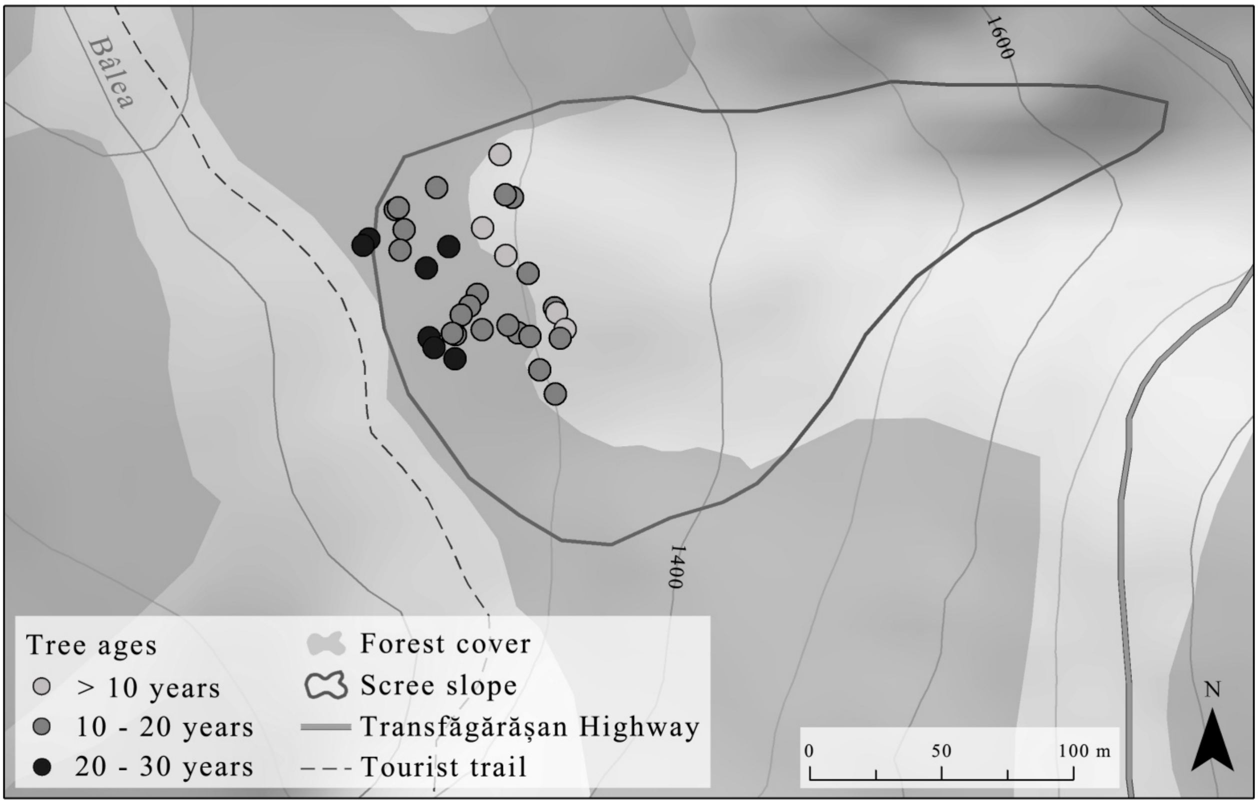

Figure 3. Relative ages of trees on the scree slope

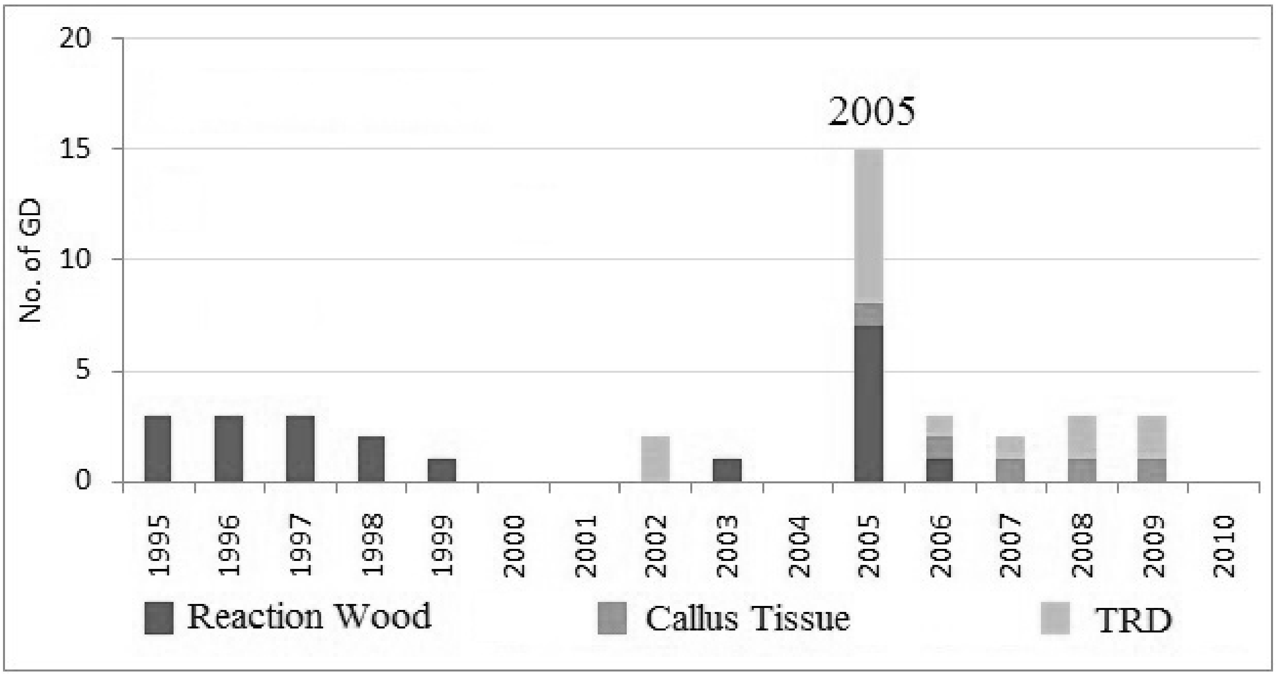

Figure 4. Event-response histogram showing the type and amount of GD identified in disturbed trees

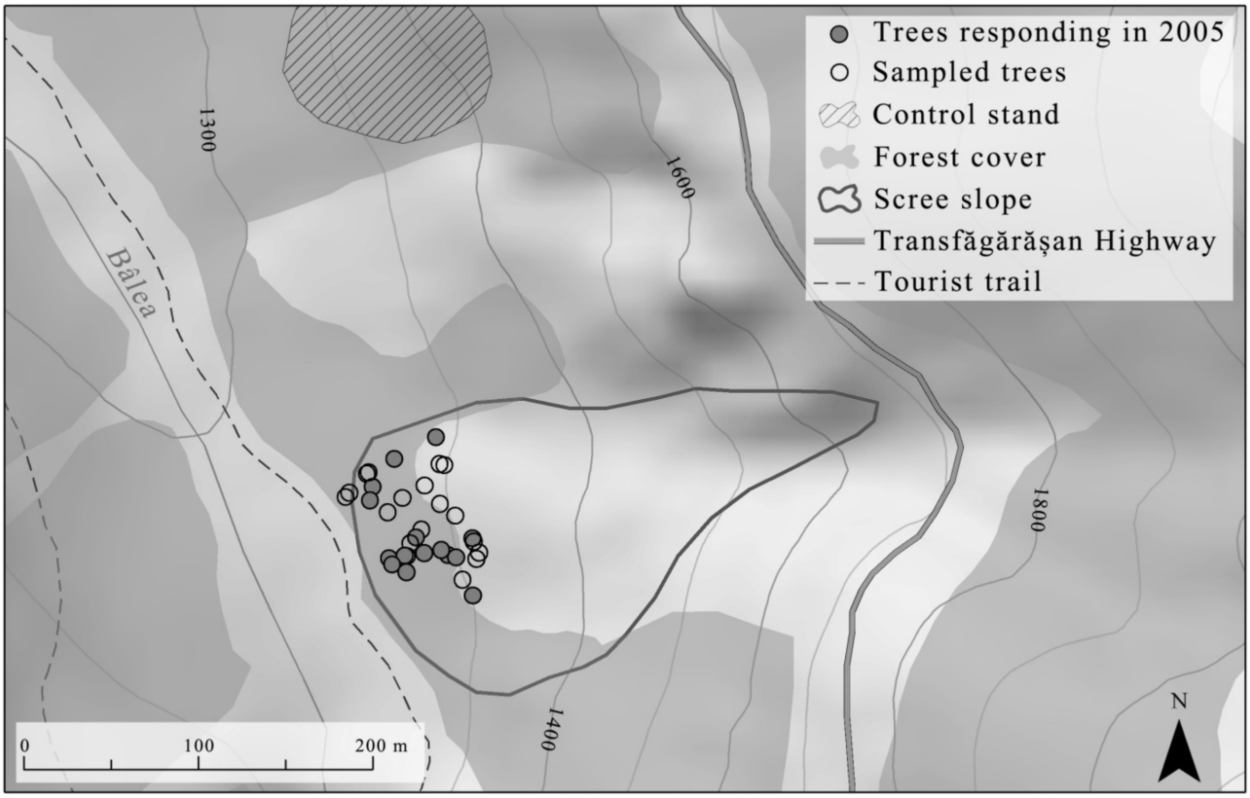

Figure 5. Spatial distribution of trees affected by the 2005 snow avalanche

This major event affected 16 trees located both in the central part of the stand and in the north-western corner (see Fig. 5), suggesting that a large amount of snow was involved. Recent tree-ring based studies (Voiculescu & Onaca, 2013, 2014, Chiroiu et al., 2015) and recordings of the Nivometeorology Programme within the National Administration of Meteorology (ANM, 2005) report intense snow avalanche activity in the Southern Carpathians in spring 2005. Numerous and major avalanches have been prepared and triggered under natural conditions in March and April 2005 (ANM, 2005, Voiculescu & Ardelean, 2012). The reconstruction of the 2005 event proves that the area investigated in our study follows a natural regime regarding the manifestation of major snow avalanches.

Dendrochronological analysis of *P. abies* trees growing at the study site enabled us to assess the relative age of two investigated forest stands. Results show that the oldest tree sampled on the scree exhibited 30 annual rings at disturbance height, whereas the mean age of the control stand is 98 years, with a minimum of 78 years. The two compared forest stands are visually discrepant and exhibit different forest dynamics (Voiculescu et al., 2013). While the forest colonizing the lower part of the scree is composed of young *P. abies* trees and flexible pioneer species such as *Alnus viridis*, the control stand exclusively consists of mature *P.abies* trees. The comparative dendrochronological results suggest a complete deforestation of the area where the scree is nowadays extending.

Slope processes such as rockfall and snow avalanches appear to be currently active on the scree slope, but this has not been the case before the road construction started. Aerial photographs of the investigated area - dating from the 1960s (see Fig.6) - display a homogenous forest, with no scree slopes yet developed.

Our dendrochronological analyses, in conjunction with aerial photograph evidence, confirm the hypothesis of a complete deforestation at the study site, most probably during the construction of the alpine road.

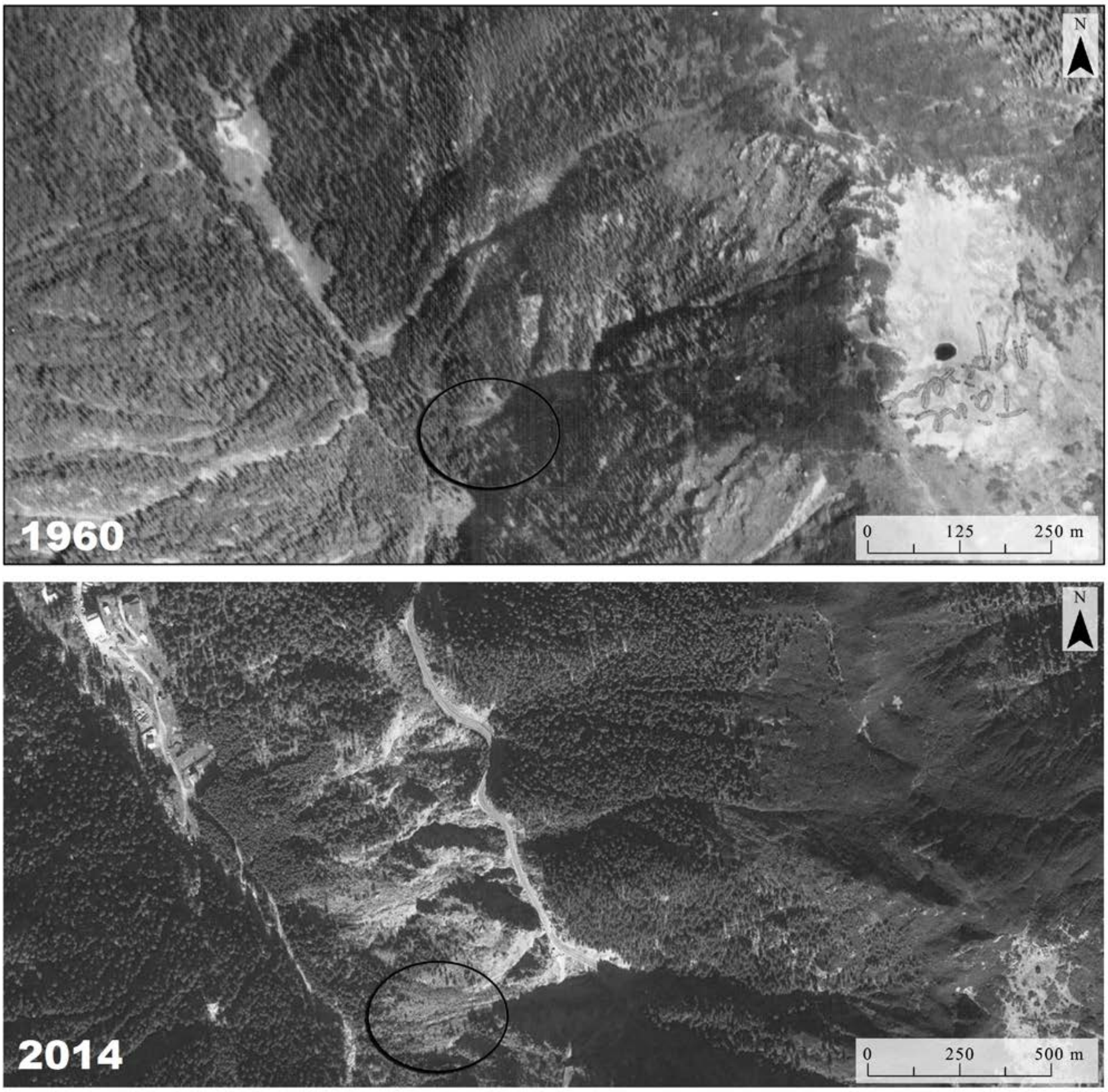

Figure 6. Two aerial photographs from 1960 and 2014 (source: Google Earth, 2014) of the investigated area, showing landscape and forest cover changes induced by road construction activities.

Afterwards, the cleared area started to develop naturally, and while a complex system of activated slope processes are shaping the landscape, its anthropogenic origin is hiding underneath. Trees started to re-colonize the cleared area in the late 1970s, but complete reforestation is currently hampered by the manifestation of various geomorphic processes.

Human activities in high mountain environments are not only capable of leaving clear marks upon the natural landscape, but as the present study shows, they sometimes create a frame for activating, intensifying or stimulating geomorphic slope processes. In addition, road traffic influences the frequency and magnitude of such phenomena - for instance, rockfall rates could be amplified by the vibrations induced by passing vehicles. On the other hand, during the cold season, when the Transfăgărășan Highway is closed for traffic, slope processes such as snow avalanches follow the local natural regime of occurrence.

6. CONCLUSIONS

In the present paper, tree-ring based techniques have been employed to analyze recent geomorphic disturbance in a *P. abies* forest located in the lower part of a scree slope and, concurrently, to evaluate the anthropogenic impact upon the studied area. We have identified continuous geomorphic activity beginning with the mid 1990s. The scree lies right beneath the runway of an alpine road in the Făgăraș Mountains - Romanian Carpathians, raising the question of natural versus human-induced evolution of the slope. Our results suggest a natural regime at least regarding the manifestation of snow avalanches.

Based on the relative tree ages obtained for two neighboring forest stands, we were able to detect the anthropogenic origin of the studied scree. Our results are validated by aerial photographs from the 1960s which exhibit a homogenous, undisturbed forest colonizing the investigated area. We hereby demonstrate the feasibility of dendrochronology in identifying and analyzing sites which have been presumably created or severely influenced by human activities in areas where no other evidence is available.

Acknowledgements

The authors acknowledge the insightful feedback of two anonymous reviewers and the help of the editor. This study received financial support from the POSDRU/159/1.5/S/133391 project, part of the Sectorial Operational Programme for Human Resource Development 2007–2013.

REFERENCES

Alestalo J., 1971. *Dendrochronological interpretation of geomorphic processes*. Fennia nr. 105, Helsinki, 1-140.

Administrația Națională de Meteorologie, 2004–2005. *Bilanțul nivologic, sezonul nivologic 2004-2005*, Secția de Meteorologie Dinamică, Climatologie si Agrometeorologie, Grupul de Verificare a Prognozelor si Adaptare Statistica, Colectivul de Nivometeorologie, București.

Braam R.R., Weiss E.E.J. & Burrough P.A., 1987. *Spatial and temporal analysis of mass movement using dendrochronology.* Catena 14, 573-584.

Bräker, O.U., 2002. *Measuring and data processing in tree-ring research — a methodological introduction*. Dendrochronologia 20, 203–216.

Bruschi, V.M., Forte, L.M., Bonachea, J., Remondo, J., Rivas, V. & Cendrero, A., 2011. *Evidences of major changes in Earth's surface processes. Should the Anthropocene be considered as a new period in geologic history?* IAG/AIG Regional Conference. Geomorphology for human adaptation to changing tropical environments. Addis Ababa, Ethiopia, p. 37.

Bruschi, V.M., Bonachea, J., Remondo, J., Gómez-Arozamena, J., Rivas, V., Méndez, G., Naredo, J.M., Cendrero, A., 2013. *Analysis of geomorphic systems' response to natural and human drivers in northern Spain: Implications for global geomorphic change*, Geomorphology 196, pp. 267–279.

Burrows C.J., Burrows V.L., 1976. *Procedures for the study of snow avalanche chronology using growth layers of woody plants*. Institute of Arctic and Alpine Research, Occasional Paper 23, 1-54.

Butler D.R. & Malanson G.P., 1985. *A history of high-magnitude snow avalanches, southern Glacier National Park, Montana, U.S.A*. Mountain Research and Development, 5 (2), 175-182.

Casteller A., Villalba R., Araneo D. & Stoeckli V., 2011. *Reconstructing temporal patterns of snow avalanches at Lago del Desierto, Southern Patagonian Andes*. Cold Regions Science and Technology 67 (2011) 68-78.

Chiroiu, P., Stoffel, M., Onaca, A. & Urdea, P., 2015. *Testing dendrogeomorphic approaches and thresholds to reconstruct snow avalanche activity in the Făgăraș Mountains (Romanian Carpathians),* Quaternary Geochronology 27, 1-10.

Corona C., Rovéra G., Lopez Saez J., Stoffel M. & Perfettini P., 2010. *Spatio-temporal reconstruction of snow avalanche activity using tree rings: Pierres Jean Jeanne avalanche talus, Massif de l'Oisans, France*. Catena 83, 107-118.

Corona C., Lopez Saez J., Stoffel M., Bonnefoy M.,

Richard D., Astrade, L. & Berger F., 2012. *How much of the real avalanche activity can be captured with tree rings? An evaluation of classic dendrogeomorphic approaches and comparison with historical archives*. Cold Regions Science and Technology 74–75, 31–42.

Germain D., Filion L. & Hétu B., 2009. *Snow avalanche regime and climatic conditions in the Chic-Choc Range, eastern Canada.* Climatic Change 92, 141-167.

Goudie, A.S., 2005. *Human Impact on the Natural Environment. Past, present and future*. 6th Edition. Blackwell Publishing, Oxford. 376 p.

Gregory, K.J. & Walling, D., 1987. *Human Activity and Environmental Processes*. John Wiley and Sons, Chichester. 482 p.

Holmes, R.L., 1983. *Computer-assisted quality control in tree-ring dating and measurement*. Tree-Ring Bulletin 43, 69–75.

Janke, J. & Price, L., 2013. *Mountain landforms and gromorphic processes* in Price, M., Byers, A., Friend, D., Kohler, T., Price, L., (eds.) Mountain Geography: Physical and Human Dimensions, 127-166.

Juknys, R., Vencloviene, J.,Vitas, A., Augustaitis, A., Kliucius, A. & Bartkevicius, E., 2014. *Dynamic response of tree growth to changing environmental pollution*, European Journal of Forest Research (133), 713-724

Loczy, D. & Sütö, L., 2011. *Human activity and geomorphology*, in The SAGE handbook of geomorphology, eds. Kenneth J. Gregory & Andrew S. Goudie, SAGE, Los Angeles, 267-286.

Lopez Saez, J., Corona, C., Stoffel, M., Gotteland, A., Berger, F. & Liébault, F., 2011. *Debris-flow activity in abandoned channels of the Manival torrent reconstructed with LiDAR and tree-ring data*. Natural Hazards and Earth System Science 11, 1247–1257.

McClung, D.M. & Schaerer, P.A., 2006. *The avalanche handbook*, The Mountaineers Books. 3rd revised.

Motta, R., Nola, P., 2001. *Growth trends and dynamics in sub-alpine forest stands in the Varaita Valley (Piedmont, Italy) and their relationships with human activities and global change*, Journal of Vegetation Science Vol. 12 (2), 219–230

Petrescu, E., 2014. *Nicolae C. Mazilu. Biobibliographic documentary Rom: Nicolae C. Mazilu. Documentar biobibliografic*, Editura Antim Ivireanul, Râmnicu Vâlcea, 168 p.

Pop, O., Buimagă-Iarinca, S., Anghel, T. & Stoffel, M., 2014. *Effects of open-cast sulphur mining on sediment transfer and toxification of riparian forests*, Geografiska Annaler Series A Physical Geography 96 (4), 485-496.

Reardon B.A., Pederson G.T., Caruso C.J. & Fagre D.B., 2008. *Spatial reconstructions and comparisons of historic avalanche frequency and extent using tree rings in Glacier National Park, Montana, USA.* Arctic, Antarctic, and Alpine Research 40, 148-160.

Rinn, F., 2013, *TSAP-Win. Time Series Analysis and Presentation for Dendrochronology and related Applications. User Reference*. Frank Rinn. Heidelberg. 90 p.

Rolland, C., Petitcolas, V. & Michalet, R., 1998. *Changes in radial tree growth for Picea abies, Larix Decidua, Pinus cembra and Pinus uncinata, near the alpine timberline since 1750*, Trees (13), 40-53.

Shroder, J.F., 1978. *Dendro-geomorphological analysis of mass movement on Table Cliffs Plateau, Utah*. Quaternary Research 9, 168–185.

Shroder Jr., J.F., 1980. *Dendrogeomorphology: review and new techniques of tree-ring dating.* Progress in Physical Geography, 4 (1), 161-188.

Slaymaker, O., Spencer, T. & Embleton-Hamann, C., 2009. *Geomorphology and global environmental change*. Cambridge University Press, London. 434 p.

Stoffel M., Schneuwly D., Bollschweiler M., Lièvre I., Delaloye R., Myint M. & Monbaron M., 2005. *Analyzing rockfall activity (1600-2002) in a protection forest — a case study using dendro geomorphology.* Geomorphology 68 (3-4), 224-241.

Stoffel, M. & Perret, S., 2006. *Reconstructing past rockfall activity with tree rings: some methodological considerations.* Dendrochronologia 24, 1–15.

Stoffel M. & Bollschweiler M., 2008. *Tree-ring analysis in natural hazards research – an overview*. Natural Hazards and Earth System Sciences 8, 187-202.

Stoffel M., 2008. *Dating past geomorphic processes with tangential rows of traumatic resin ducts*. Dendrochronologia 26 (1), 53-60.

Stoffel M. & Bollschweiler M., 2009. *What tree rings can tell about earth-surface processes. Teaching the principles of dendrogeomorphology*. Geography Compass 3, 1013-1037.

Stoffel, M., Butler, D.R. & Corona, C., 2013. *Mass movements and tree rings: A guide to dendrogeomorphic field sampling and dating.* Geomorphology 200, 106–120.

Stoffel, M. & Corona, C., 2014. *Dendroecological dating of geomorphic disturbance in trees.* Tree-Ring Research70(1), 3-20.

Syvitski, J.P.M., Kettner, A., 2011. *Sediment flux and the Anthropocene. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* 369 (1938), 957–975.

Szabó, J., Dávid, L. & Lóczy, D., 2010. *Anthropogenic Geomorphology. A guide to man-made landforms,* Springer, Heidelberg, 298 p.

Szabó, J., 2010 - *Anthropogenic Geomorphology. Subject and System,* in J. Szabó et al. (eds.), Anthropogenic Geomorphology, pp.3-10.

Szymczak S., Bollschweiler M., Stoffel M. & Dikau R., 2010. *Debris-flow activity and snow avalanches in a steep watershed of the Valais Alps (Switzerland):*

Dendrogeomorphic event reconstruction and identification of triggers. Geomorphology 116 (2010) 107-114.

Thomas, W., 1956. *Man's Role in Changing the Face of the Earth I–II.* University of Chicago Press, Chicago. 1236 p.

Timell T., 1986. *Compression wood in gymnosperms*. Springer, Berlin.

Trappmann, D. & Stoffel, M., 2013. *Counting scars on tree stems to assess rockfall hazards: a low effort approach, but how reliable?* Geomorphology 180–181, 180–186.

Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Mathews, J.T. & Meyer, W.B., 1990. *The Earth as Transformed by Human Action.* Cambridge University Press, Cambridge.729 p.

Urdea P., 2000. *The geomorphological risk in Transfăgărășan Highway area*. Studia Geomorphologica Carpatho-Balcanica. Vol.XXXIV.

Urdea, P., Török-Oance, M., Ardelean, M., Vuia, F. & Voiculescu, M., 2009. *Geomorphological aspects of the human impact in the alpine area of the Southern Carpathians (Romania).* Croatian Geographic Bulletin (71), No.1, 19-31.

Varnes, D.J., 1978. *Slope Movement Types and Processes*. In Special Report 176: Landslides: Analysis and Control (R.L. Schuster and R.J. Krizek, eds.), TRB, National Research Council, Washington, D.C., 11-33.

Voiculescu, M., Ardelean, F., Onaca, A. & Török-Oance, M., 2011. *Analysis of snow avalanche potential in Bâlea glacial area - Făgăraș massif (Southern Carpathians - Romanian Carpathians)*, Zeitschrift für Geomorphologie, Vol.55 (3), 291-316.

Voiculescu M. & Ardelean F., 2012. *Snow avalanche - disturbance of high mountain environment. Case study - the Doamnei glacial valley the Făgăraş Massif – Southern Carpathians, Romanian Carpathians*. Carpathian Journal of Earth and Environmental Sciences, February 2012, Vol. 7, No. 1, 95-108.

Voiculescu M., Onaca A. & Chiroiu P., 2013. *L'analyse de la dynamique forestiere et de l'impact mecanique des avalanches de neige sur les arbres en utilisant la methode dendrochronologique*. Panorama de la dendrochronologie en France.

Voiculescu, M. & Onaca, A., 2013. *Snow avalanche assessment in the Sinaia ski area (Bucegi Mountains, Southern Carpathians) using the dendrogeomorphology method*. Area 45 (1), 109-122.

Voiculescu, M. & Onaca, A., 2014. *Spatio-temporal reconstruction of snow avalanche activity using dendrogeomorphological approach in Bucegi Mountains Romanian Carpathians*. Cold Regions Science and Technology 104-105, 63-75.

Voiculescu, M., 2014 - *Patterns of the dynamics of human-triggered snow avalanches at the Făgăraș massif (Southern Carpathians), Romanian Carpathians*, Area, Vol.46 (3), 228-342.

Wick, L., Lemcke, G. & Sturm, M., 2003 - *Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey*, The Holocene vol.13 (5), 665-675.

Received at: 31. 01. 2015
Revised at: 19. 09. 2015
Accepted for publication at: 25. 09. 2015
Published online at: 01. 10. 2015