PHYTOLOGIA BALCANICA 17(2): 237–246, Sofia, 2011

Avalanches on the northwestern slope of peak Todorka (Pirin Mts, SW Bulgaria) and their influence on forests

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Received: March 10, 2011 ▹ Accepted: June 05, 2011

Abstract. We studied the avalanche activity on the northwestern slope of peak Todorka in the Pirin Mts (SW Bulgaria) and its influence on forests. The terrain was mapped by building a digital elevation model (DEM) from the topographical maps and with the help of aerial photographs. The terrain characteristics of the slope were found suitable for the formation of big avalanches and over 30 % of the potential forest area was seriously affected by avalanches. Seven percents of the forests were destroyed by avalanches repeatedly or during the last 50 years. The total area of the avalanche paths into the forests was 4.7 ha. The structure and composition of the forest community in a representative runout zone was highly dependent on avalanche frequency. The author maintains that, despite their high ecological role and threat to human health and life, avalanches on the NW slope of peak Todorka are neglected and studied inadequately.

Key words: avalanches, peak Todorka, *Pinus peuce* forests, Pirin Mts

Introduction

Avalanches are among the major natural disturbances (Bebi & al. 2009). They can inflict grave damage on centuries-old forests, infrastructure, buildings, and take away human lives (Peev & Dimitrov 1971; McClung & Shaerer 1992; Weir 2002). In regions with steep mountain slopes and abundant snow precipitation avalanches shape out the structure and composition of the ecosystems, affecting primarily the stationary species growing above the average snow-depth, such as trees and high shrubs (Vlasov & al. 1980; Butler & Malanson 1985; Patten & Knight 1994; Weir 2002). This in turn affects indirectly the small plants, animals and insects. Avalanche runout zones frequently have high biodiversity and are very important for the existence of certain species (Mace & al. 1996; Weir 2002; Rixen & al. 2007; Bebi & al. 2009). Thus, in many parts of the world such areas have been recognized as important from a conservation viewpoint. While avalanches have an important impact on the forest structure, forests also influence the magnitude and frequency of avalanches (Bebi & al. 2009). Their role for the protection of human settlements has been recognized since the Middle Ages in the European Alps (Price & al. 1997) and widely used in recent decades (Brang & al. 2006; Teich & Bebi 2009). Currently, there is an increasing awareness of the interaction between forest ecosystems and avalanches (see Bebi & al. 2009). Still, there is concern that climate change may influence avalanche magnitude and frequency (Schneebeli & al. 1997) and hence the role of avalanches on mountain ecosystems. Another concern of the forest managers is the interaction of avalanches with other disturbances, such as windthrows and fires, which are accepted as processes within the natural range of variability of subalpine forests (Kulakowski & Bebi 2004). While recent studies of windthrow areas in the European Alps demonstrate that, if fallen logs are not removed, the avalanche protection function is retained (Frey & Thee 2002; Schonenberger & al. 2005), the slow regeneration of tree species at high altitudes (Tranquillini 1979) explains a certain concern for maintaining the protection functions in the future. If the remaining wood debris cannot prevent snow gliding, a risk of formation of new avalanche paths exists. On the other hand, when protection functions are not an aim as, for example, in natural forests without infrastructure and settlements, avalanche paths in forests may be considered as valuable fragmentation breaks important as natural fire fuel breaks (Malanson & Butler 1984a) or animal habitats (Nikolov 2009).

Studies of the protection and other functions of forests in avalanche terrain gain increasing importance within the framework of intentions to manage more subalpine forests in a nature-oriented manner. In such cases it is very important to know the natural range of variability of these ecosystems (i.e. the most important natural disturbances and dynamics of forests). Yet, the long tradition of forest use by humans in the European mountains sets difficulties in finding natural examples for such studies. Research in protected areas without management history in the recent past is an opportunity. Among such examples are some of the forests in the Pirin National Park in Bulgaria. The steepness of slopes and abundant winter precipitation create conditions for high avalanche activity (Peev & Klecharov 1976; Panayotov 2000), while the poor accessibility of high-mountain forests has made them unattractive for intensive management either by logging or pasturing. This helped forests to retain their natural structure shaped out mainly by avalanches and fires (Panayotov & Yurukov 2007). As the dominant species in the subalpine forests of the Pirin Mts (*Pinus peuce* Griseb. and *Pinus heldreichii* Christ) are rare relict endemic and sub-endemic species and thus they are under national and international protection (Farjon & al. 1993), study of their disturbance regime is of further importance. Yet, so far there have been only few avalanche activity studies in the Pirin Mts (Peev 1955; Peev & Dimitrov 1971; Peev & Klecharov 1976; Panayotov 2000, 2007a,b). They address specific moments or locations with avalanche activity and are published in Bulgarian language, which hinders further the international scientific community in getting acquainted with the available results. Along with this, attention has been increasingly drawn to avalanches, mainly because of the risk they pose to the recently constructed ski facilities and the ever growing number of incidents with skiers and snowboarders (Panayotov 2006). Still, no regular observations of snowpack and avalanche activity have been maintained, nor any continuous historic records exist. This poses further difficulties in avalanche studies and requires the use of indirect methods for obtaining information, such as vegetative indicators analysis (Carrara 1979; Butler & Malanson 1985; Patten & Knight 1994; Casteller & al. 2007).

Our aim was to present a study on the importance of the avalanche activity for the forests on the northwestern slope of peak Todorka (Pirin Mts). It is representative of a typical slope in this mountain range, with a main peak (2748 m a.s.l.) above the treeline, altitude difference of the slope of almost 1000 m, and natural forests with numerous avalanche paths below 2250 m a.s.l. Furthermore, it is at the border of the Bansko ski area, which provides an easy access to numerous backcountry skiers and snowboarders. At the foot of the slope there are infrastructure facilities, such as water-catchments, a bridge and a road. All these factors require a thorough knowledge of the avalanche regime of the slope and its impact on the available ecosystem and structures.

Material and methods

Study site

The study site is the northwestern slope of peak Todorka (2748 m a.s.l., 41°45'9"N, 23°25'55"E) in the Pirin Mts, Southwest Bulgaria (Fig. 1). To the north its border is a shoulder descending from the main ridge of the peak from point with coordinates 41°45'58"N, 23°26'08"E. To the south the study site boundary lies on the border of a famous avalanche couloir ("Trizabetsa", marked with "c8" on Fig. 1), which descents to Vihren hut from point with coordinates 41°44'58"N, 23°25'38"E. The top of the study site follows the main ridge of the peak, while the bottom runs along the bed of river Banderitsa. Thus defined zone encompasses eight main couloirs known as the "Banderitsa chutes" and the forests on the ridges between them.

The climate in the study region is typical for a high mountain location and is strongly influenced by Mediterranean air masses. The mean annual temperature (Vihren Chalet Climate Station, 1970 m. a.s.l.) is 3.5°C. It ranges from a mean monthly temperature of –4.7 °C in January to +12.2 °C in August. The annual precipitation amounts to 1378 mm, with a maximum in autumn and winter. A difference from the other

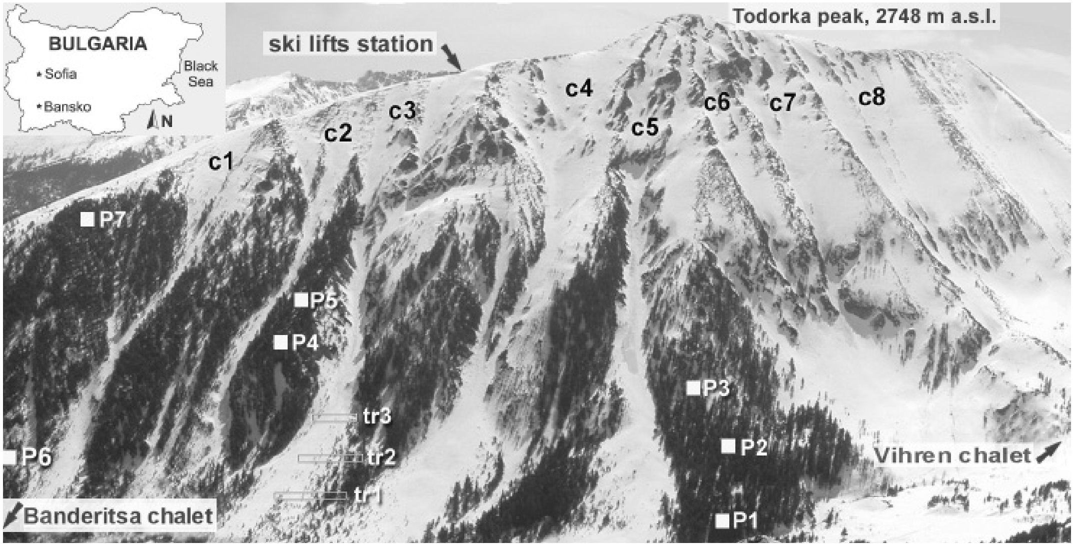

Fig. 1. Study slope. Couloirs are labeled with "c" and a serial number, sample plots with "P" and a serial number, and transects with "tr" and a serial number.

high mountains in Bulgaria (e.g., Rila and Stara Planina) is that the Pirin mountain range serves as a barrier for advancing southwestern Mediterranean air masses, which are more frequent during the autumn-winter period (Brown & Petkova 2007). Deep snow cover, frequently exceeding 2 m, is typical for the region. The absolute maximum snow depth for Bulgaria (472 cm) was recorded at the Vihren Chalet Station.

Soils are Umbric and Modic Cambisols, formed on granite bedrock. At the northwestern end of the study site there is a small region with Rendzic Leptosols and Regosols formed on marble bedrock. The forests are composed mainly of the Balkan endemic species *Pinus peuce* Griseb. (Macedonian Pine). In the lower parts (i.e. up to about 1900 m a.s.l.), Norway Spruce (*Picea abies* (L.) H.Karst.) and Scots Pine (*Pinus sylvestris* L.) have limited participation. Bosnian Pine (*Pinus heldreichii* Christ) is also found in the zone with marble bedrock. Above the timberline, the dwarf shrub form of the Mountain Pine (*Pinus mugo* Turra) and Common Juniper (*Juniperus communis* L. *var. nana; J. sibirica* Burgst.*)* form dense communities.

Terrain mapping

We digitalized the existing topographic maps of the studied slope at a scale 1:5000 with ArcGIS 9.1 and on their basis created a digital elevation model (DEM) (McCoy & al. 2001). Using DEM, we composed high-resolution digital models (maps) of inclination, slope exposure, and calculated the vertical differences, length and area of the avalanche routes. To achieve accurate mapping of the forests and shrub communities, we used a SPOT satellite image from August 2008. A "false-colour image" was composed, with band combination "432", known also as a "false colour infrared" combination (Coppin & al. 2004). This colour combination allows an easy detection of rocks which appear light-blue, coniferous forests which appear dark-green, and grasslands which appear pink. Furthermore, we used high-resolution aerial photographs from 1997 for a more precise mapping (i.e. resolution allowing single-tree detection) of the forest communities and avalanche paths. Since these photographs were not originally orthorectified, it was necessary to perform to absolute orientation, in order to generate orthophotos. Leica Photogrammetry Suite (LPS 9.1) was used for the purpose (Leica 2003). Ground control points were derived from the GPS field measurements, existing satellite data and Google Earth software (Google Inc.). Orthorectification was done in WSL-Birmensdorf by L. Laranjeiro.

Vegetative analysis

To obtain data for forest structures, we have set six rectangular study plots of 0.2 ha (40×50 m) in various locally representative sites (Fig.1). Within them we recorded tree diameter at breast height (DBH), saplings presence and took cores for tree ring analysis. These plots were at locally elevated ridges and thus did not experience frequent avalanche activity. In the runout zone of the avalanche couloir No. 3 we set three rectangular transversal transects with dimensions 10×100 m to 10×150 m (Fig.1). To describe vegetation changes more accurately, each transect was subdivided into 10-meter sections. The first transect with a length of

150 m was set at the lower part of the avalanche runout zone (1835 m a.s.l.), starting from the central part, where avalanches are frequent, and going southwards towards the peripheral forest. The second transect (150 m long) was set in the middle part (1860 m a.s.l.) of the runout zone, also starting from its centre and going southwards. The third transect (100 m long) was set in the top part (1925 m a.s.l.) of the runout zone and ran lengthwise in the north-south direction. Thus transects reflected the shrub and tree transition from the central to the peripheral zones in subregions with varying avalanche intensity, mostly according to their recurrence period, i.e. annual to decadal avalanche impact (Malanson & Butler 1984). In the transects we recorded basic coverage classes: rock screes, grass patches, shrubs and trees. Detailed data was collected on the shrub and tree species presence, tree height and age. The age was determined by extraction of tree ring cores and whorl-counting. The core extraction was done with an increment borer in two opposite directions – up and down the slope, usually at 0.5 m above ground. The tree ring samples were mounted on wooden holders, air-dried and sanded with gradual reduction of the grain size, in order to make anatomical features distinguishable. Then they were measured with accuracy of 0.01 mm in the tree-ring laboratory of the University of Forestry in Sofia. Crossdating was performed, following the standard procedures by visual (Stokes & Smiley 1968) and numerical analysis with COFECHA software (Holmes 1983).

Results

Terrain characteristics of the studied slope

On the NW slope of peak Todorka there are eight well-defined main couloirs separated by elevated ridges (Fig. 1). According to our terrain model, slope inclination varies from 20 to 50 degrees (Fig. 2). In the lowest parts of the slope, where the runout zones of the avalanche couloirs are situated, slopes are close to 20 degrees. The vertical drop of the couloirs varies between 600 m and 875 m, the average inclination is between 34 and 40 degrees (Table 1). The biggest snow-catchment area was calculated for couloir No. 4 (15.6 ha), and the smallest for couloir No. 6 (5.9 ha) (Fig. 2).

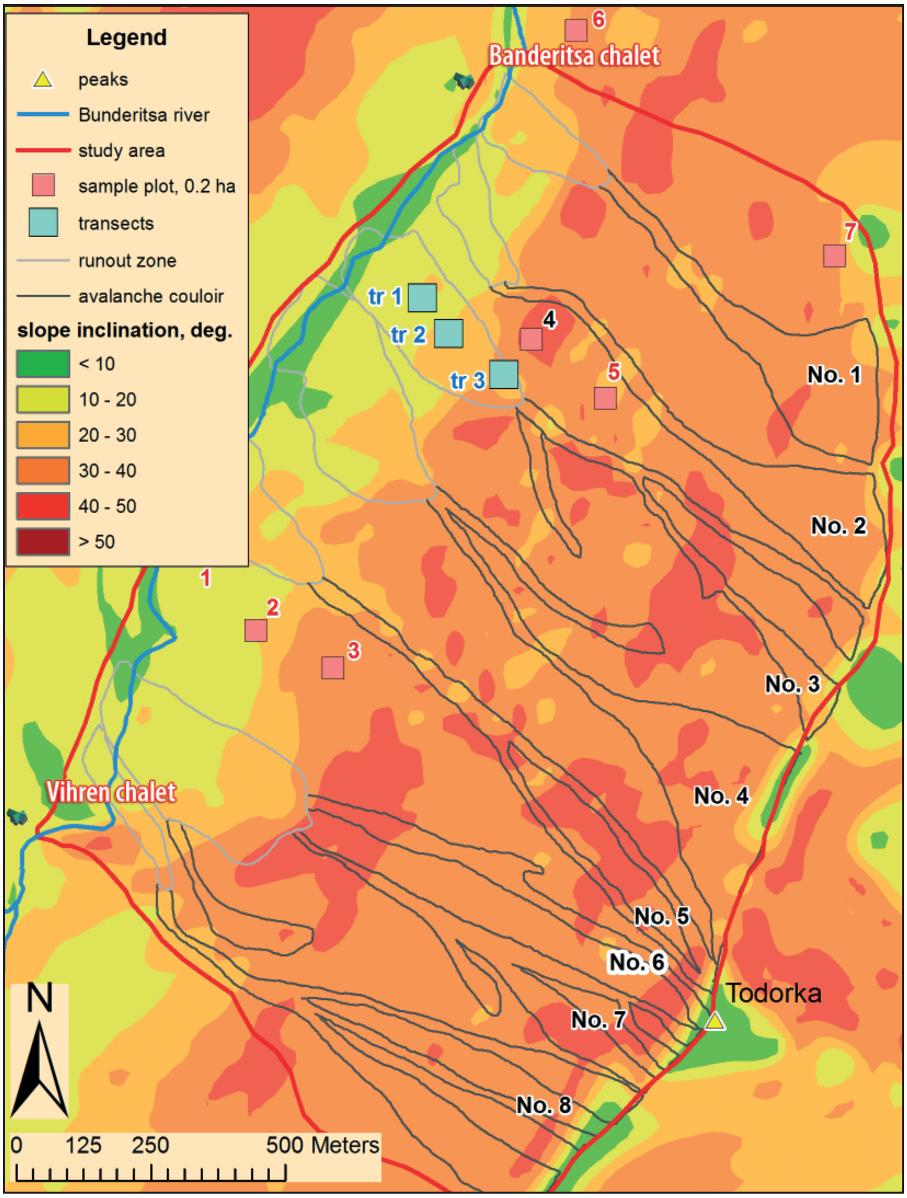

Fig. 2. Slope inclination and main avalanche couloirs on the NW slope of peak Todorka, Pirin Mts.

Table 1. **General features of avalanche couloirs on the NW slope of peak Todorka, Pirin Mts**

Couloir No.	Snow-catchment area, ha	Vertical drop, m	Length of avalanche couloir, m	Length of runout zone, m	Average inclination of avalanche couloir, deg	Average inclination of runout zone, deg
1	6.3	625	1190	310	34	27
2	6.1	700	1355	210	34	21
3	10.1	730	1400	405	37	21
4	15.6	875	1670	370	38	20
5	11.1	850	1525	290	37	21
6	5.9	825	1485	385	40	21
7	10.7	825	1450	350	40	21
8	16.2	775	1385	205	38	19

An important feature of the NW slope of peak Todorka is that most snow accumulation zones lie at inclination between 30 and 40 degrees. Steeper rock ridges are present above 2500 m a.s.l. on the borders between the couloirs Nos 4 and 5, 5 and 6 and 6 and 7. The steepest sections of the slopes below 2400 m a.s.l. are often just above or within the vertical belt where forests grow (i.e. in the middle of the slope). Furthermore, on some ridges the length of slopes above the treeline exceeds several hundred meters. Exposure is predominantly NW. Only on the ridges between the couloirs there are slopes with W exposure, which are mostly occupied by forests (Fig. 3). North exposures are found on steep slopes descending from the ridges towards the couloirs.

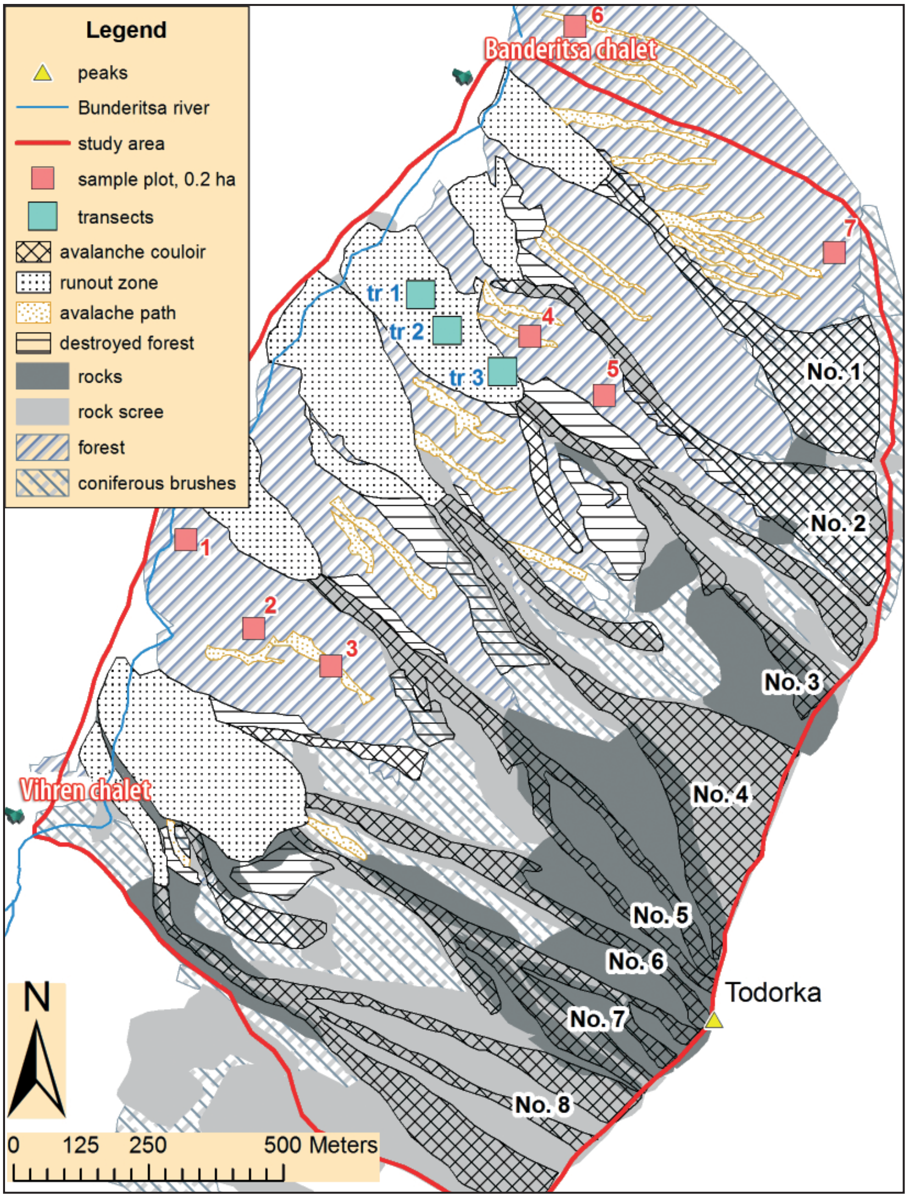

Fig. 3. Forest coverage and avalanche activity zones on the NW slope of peak Todorka.

Forest interaction with avalanches

The forests occupy 104 ha on the studied slope (48 %). They were situated on the elevated ridges between the couloirs where falling avalanches affected them to a lower degree. The treeline was situated between 2200 m and 2250 m a.s.l. Only in the northern part of the slope the forests climbed to the main ridge (2300 m a.s.l.). The predominant species was *Pinus peuce* (Table 2). Only in one plot (No. 6), at the lowest position and on calcic soils, *Picea abies* and *Pinus heldreichii* had higher participation than *P. peuce*. Tree density varied strongly. It was highest in younger forest patches (plots Nos 1 and 7), which still underwent a self-thinning phase, and probably resulted from fires or big avalanches in the past (Panayotov 2007b). In older patches (plots Nos 2–3) density of trees with DBH > 6 cm was lower. Density of saplings varied also: in higher numbers if well regenerated gaps were present, as in plot No. 3. Diameter distributions were mostly reverse J-shaped (plots 1, 3 and 6), bimodal (plots 2, 4 and 5), or unimodal (plot 7) (data not shown). The maximum age found in a core from the plots was 350 years, and 615 years from a core outside the plots (Panayotov & Yurukov 2007).

Table 2. Forest characteristics in sample plots on the NW slope of peak Todorka

Plot No.	Altitude, m a.s.l.	Species participation, % *				Trees, number/ha	Saplings, number/ha	Max. DBH, cm	Standard deviation of DBH	Max. age
		PIPE	PIHE	PCAB	ABAL					
1	1875	89		11		1005	455	86	45.4	120
2	1950	100				445	380	82	26.5	320
3	2025	100				680	1005	94	54.3	350
4	1935	100				390	215	78	16.1	180
5	2060	100				775	30	70	28.5	230
6	1825	16	29	53	2	735	285	70	41.3	230
7	2230	100				910	20	57	12.1	185

***Abbreviations.** PIPE – *Pinus peuce;* PIHE – *P. heldreichii;* PCAB – *Picea abies;* ABAL – *Abies alba*

More than one-third (31.6 %) of the potential forest area (i.e. below the local treeline and outside rock screes and avalanche couloirs) was seriously affected by avalanche activity. Most of these affected forests (22 %) were avalanche-transformed forest communities in the avalanche runout zones. Seven hectares (7 % of the total forest area) were forests destroyed during the last 50 years or repeatedly by avalanches. They were situated mostly in the bordering areas of avalanche transition zones and thus were affected by unusually big avalanches. The total territory of avalanche paths within the forests was 4.7 ha (4.5 % of the total forest area). On the average, they were 13 m wide (min. 5 m, max. 46 m) and 185 m long (min. 92 m, max. 269 m). While in some of the avalanche paths the avalanche activity in the last decades was not high and this provided a chance for regeneration to start, in others almost annual snow sliding did not permit young saplings to grow.

In the runout zone of the avalanche couloir No. 3, the maximum tree diameters varied according to the position of the trees. In the transect situated at the lower end of the runout zone, the maximum diameter in transect subsections was below 20 cm until the 110th meter from the centre towards the peripheral zone (Fig. 4). Then it increased up to 86 cm (140th meter section). No trees were found in the 40th to 50th meter of the transect (Fig. 5). The percentage of broken trees increased from 10–20 % up to 60 % in the 80th to 100th section of the transect, and then decreased to 10–30 %. The found trees were mostly *Pinus peuce*, to a lesser extent *Picea abies,* mostly in the sections from 100 m to 150 m, and occasionally single *Pinus helreichii*. In the most frequently affected zone by avalanches, namely from the beginning to the 50th meter of the transect, coverage was dominated by *Pinus mugo* and *Juniperus communis* shrub groups (Fig.5). Other species with lower participation in the total coverage were: *Vaccinium myrtillus* L., *Fragaria vesca* L., *Rubus idaeus* L., *Ribes alpinum* L., *R. petraeum*

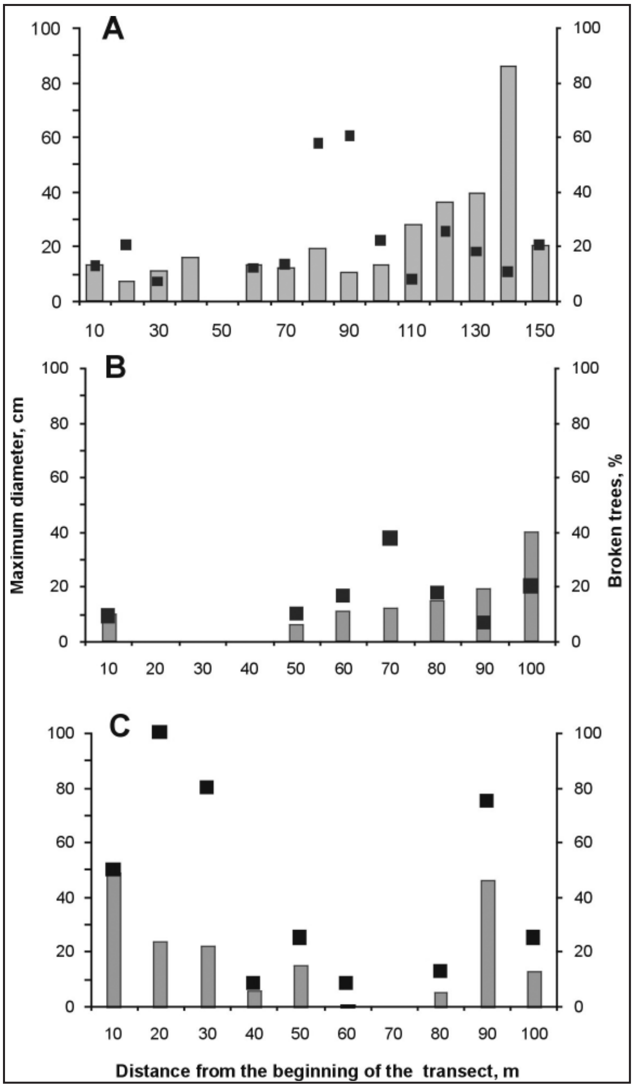

Fig. 4. Maximum diameters of trees (grey bars) and percentage of broken trees (black boxes) in the transects in the lower (A), middle (B) and top (C) parts of the runout zone of avalanche couloir No. 3 on the NW slope of peak Todorka.

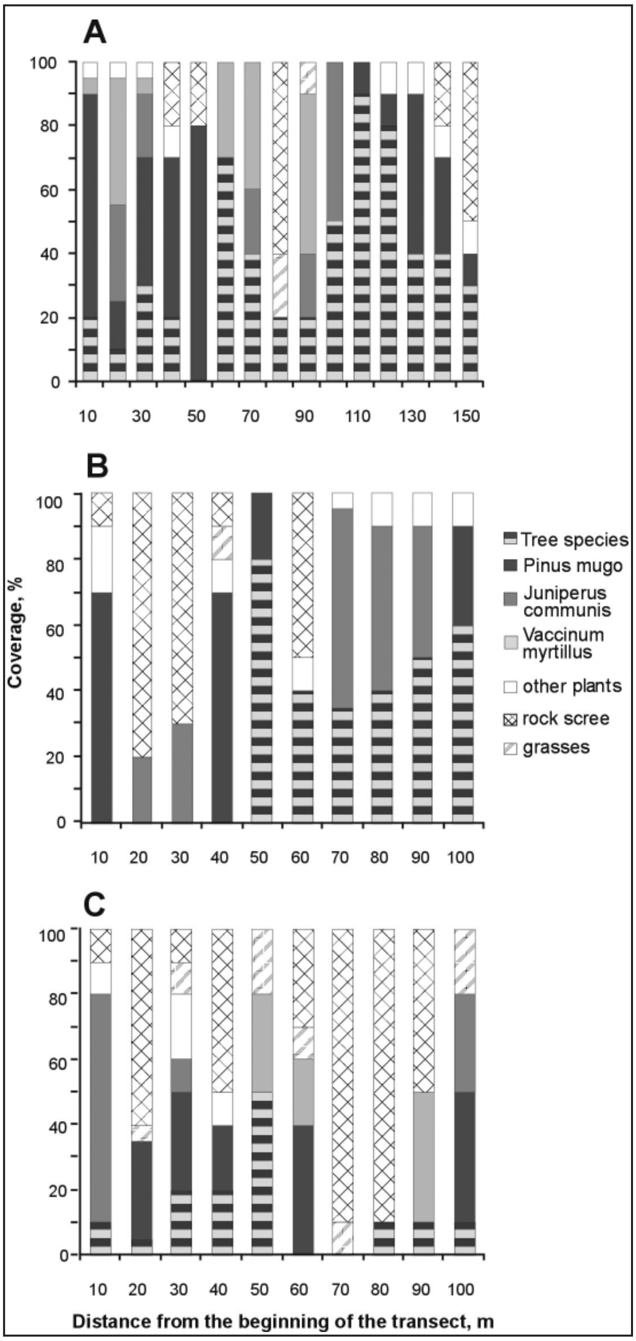

Fig. 5. Basic classes coverage in transects in the lower (A), middle (B) and top (C) parts of the runout zone of the avalanche couloir No. 3 on the NW slope of peak Todorka. Note: "Other plants" denote plant species found as single individuals in the respective transect sections. The species list is given in the text.

Wulfen, *Daphne mezereum* L., *D. oleoides* Schreb., *Chamaecytisus absinthioides* (Janka) Kuzmanov, *Lonicera caerulea* L., *L. nigra* L., *Hipericum perforatum* L., and *Cotoneaster integerrimus* Medik. From the 60th to the 140th meter, transect coverage was dominated by trees, except in the zones where rock screes did not permit their growth (80th meter section). The sections from the beginning of the transect until the 80th meter were situated in an area affected frequently by avalanches at intervals from 1 to 10 years, while the 100–140th meter sections of the transect were affected at about 20–30 year periods by bigger avalanches (Panayotov 2007a).

In the transect situated in the middle altitudinal belt of the runout zone, no trees were found from the 20th to the 40th meter (Fig. 4). These areas were occupied by rock screes, with limited coverage of *Juniperus communis* (20th to 30th meter sections) and *Pinus mugo* shrub groups (10th meter section and 40th meter section) (Fig. 5). Tree coverage was higher after the 50th meter, but with maximum diameters below 16 cm until the 70th meter section, and below 20 cm until the 90 meter section.

The transect situated in the top part of the runout zone was dominated mostly by rock screes and low shrubs, such as *Juniperus communis* and *Vaccinium myrtillus* (Fig. 5). The maximum tree diameters were found high in the peripheral zones of the avalanche couloirs (sections 0–10th meter and 80–100th meter), but in these areas over 50 % of the trees were broken repeatedly (Fig.4). In the middle part of the transect, there were either no trees or the present ones were with diameters below 10 cm.

Discussion and conclusions

From the point of view of avalanches the NW slope of Todorka peak poses high potential for formation of big avalanches. Most snow accumulation zones have inclination between 30 and 40 degrees. This contributes to higher snow-loads and less frequent, but bigger avalanches (McClung & Shaerer 1992) and, combined with a vertical drop above 500 m (up to 875 m), provides chances for big high-speed avalanches (Panayotov 2000). Historical information (Peev & Dimitrov 1971) and recent observations (Panayotov 2007b) have confirmed that the slope produces periodically big avalanches that reach the valley floor and occasionally cross the bed of river Banderitsa. Initial tree ring analysis performed by Panayotov (2007a) has also demonstrated that big avalanches had influenced the peripheral parts of the runout zone of avalanche couloir No. 3 approximately at 20–30 year periods. Another important feature of the studied slope was that the steepest parts lie often just above or within the vertical belt where forests grow (i.e. in the middle of the slope). This contributes to snow sliding within the forests. Avalanches form, when tree density is not high enough to block the snow movement. This also contributes to the continuous presence of avalanche paths within the forest. We have estimated that almost 5 % of the forest area could be classified as active avalanche paths within the forests. A historical report by Peev and Klecharov (1976) provides evidence on the snow conditions that have contributed to big enough avalanches to form new avalanche paths within the forests. According to this report, continuous snowfall at low temperatures allowed for accumulation of a thick new layer of powdery snow. On 12 Feb 1963 spontaneous avalanches cut new avalanche paths in the 100–150 year old forest in the Ikrishte region and dumped about 500 m^3 of wood in the bed of river Banderitsa. On the same date numerous avalanches fell in the avalanche couloirs on the studied and other slopes in the region. During the last 15 years, avalanches in the forests were observed mostly in two types of situations: A) powder snow avalanches during the snowfalls or soon after them, which did not cause substantial damage in that period; and B) sudden warming in the spring, which caused wet snow avalanches and broke a limited number of trees. In February 2010, a very specific situation with a soft slab lying on a week layer situated between two icy crusts was observed. It produced numerous spontaneous slab avalanches outside and within the forests and claimed two human lives, one in a forested area.

Another important fact for the avalanche-forest interaction is that on some of the ridges on the NW slope of peak Todorka the length of slopes above the treeline exceeds several hundred meters, which is enough for the sliding snow masses to gain sufficient power for damaging the trees (Vlasov & al. 1980; Gubler & Rychetnik 1991; Dufour & al. 2000; McClung & Shaerer 1992). Avalanche activity on the NW slope of peak Todorka is further influenced by the exposure. Slopes with north and northwestern exposure in the northern hemisphere are less exposed to sunlight and provide conditions for lower minimum and average temperatures (McClung & Shaerer 1992), which in turn slow down the transformation processes within the snowpack and thus prolong periods of instability.

The forest structures on the NW slope of peak Todorka depend on avalanche activity in zones where terrain allows avalanche formation and sliding. While other natural disturbances, such as fires, have probably also played a role, as evidenced by numerous burnt logs, avalanches shape forest patchiness by forming avalanche paths and maintaining avalanche couloirs free of trees. We have found that about 7 % of the forests were destroyed by big avalanches that got out of the usual avalanche pathways in the couloirs. Among the most impressive examples is the destroyed forest on the ridge between couloirs No. 4 and No. 5, which was probably affected by a powder avalanche in the early 1970s (Panayotov 2007b). Presently, most of these areas are actively regenerating and overgrown by numerous 20–30 year old trees. An exception makes the north side of avalanche couloir No. 3, where periodical avalanches at 10–20 year intervals keep the area occupied by scattered broken trees and the forest cannot recover (Panayotov 2007a). On the one hand, patchiness created by avalanches and especially problematic regeneration in avalanche paths creates concerns about the general regeneration of forests and, therefore, about their future state. Yet, we can assume that avalanches were always part of the natural disturbance regime of these forests and the fact that they still exist is evidence that that certain balance is maintained between regeneration and tree death. Furthermore, terrain characteristics with elevated ridges provide relative protection for some forest areas, which cannot be affected by normal-size avalanches. On the other hand, patchiness may provide ecological benefits. The avalanche couloirs serve as fire breaks and, therefore, fires can affect limited areas. In an earlier study (Panayotov 2007b) we have found evidence that an isolated fire about 100 years ago had affected only a limited area in the forest on the ridge between couloirs No. 2 and No. 3. In a study of bird distribution, Nikolov (2009) has found too that forest patchiness on the NW slope of peak Todorka has provided better habitats for certain species and has contributed to a higher number of birds. The presence of free-of-trees-areas also provides better conditions for regeneration of such fruit-giving species as *Rubus idaeus, Vaccinium* spp., *Fragaria vesca, Ribes* spp., and *Lonicera* spp., which ensure better feeding conditions for the forest animals. This is especially true for the avalanche runout zones, where we have found a higher proportion of shrub species than trees. The highest and central parts of the studied runout zone were occupied mostly by shrub species and rock screes. This is due to the annual avalanche activity, which does not allow bigger trees to develop. The maximum diameter of the existing trees was below 15 cm or they had suffered numerous breakages in the past. At the stage when trees have DBH below 10–15 cm, they are flexible (Bebi & al. 2009) and can bend under the snow load or the pressure of moving snow masses and remain intact. When the trees grow bigger, they stay above the snow cover and are more prone to direct impact by avalanches. Thus usually they are broken, which is reflected in our data. More than half of the trees found on the peripheral parts of the upper runout zone, which is frequently hit by avalanches, were broken. The same was true of the trees in the middle part of the lowest transect. This zone is the border between the area affected more frequently by avalanches and the area seldom hit by avalanches (Panayotov 2007a). It was occupied by bigger trees, 10–30 % of which were broken. A higher number of plant species in the avalanche paths and runout zones was found also by Rixen & al. (2007) in an extensive study of the effects of avalanches on plant diversity in the European Alps, by Malanson & Butler (1984b) in a study of vegetation in avalanche runout zone in North America, and by Vlasov & al. (1980) in a study of avalanches in the Caucasus Mountains.

Our data demonstrate that the NW slope of peak Todorka is characterized by high avalanche activity and terrain characteristics that provide conditions for the formation of frequent big avalanches. While these processes interact with forests and are within their natural range of variability, they pose high risk for skiers, snowboarders and hikers, whose numbers have steadily increased after the expansion of the Bansko Ski Resort. The lack of real measures to limit human access to the NW slope of Todorka peak during the periods with high avalanche danger or at least inform comprehensively the potential visitors for the threats increases the chances for avalanche accidents. Therefore, we consider that further measures for studying the avalanche processes, their influence on forests and interaction with current tourism development are necessary.

Acknowledgements. The author wishes to thank Ivan Gerin and Alexander Duntchev for their assistance in fieldwork. The orthorectification work performed by L. Laranjeiro at the WSL in Birmensdorf is gratefully acknowledged. Advice of P. Bebi from the SLF Institute in Davos helped improve the manuscript.

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