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THE INFLUENCE OF SNOW AVALANCHES ON THE TIMBERLINE IN THE BABIA GÓRA MASSIF, WESTERN CARPATHIANS

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Abstract

Avalanches are one of the most important abiotic factors influencing the timberline on a worldwide scale. In the case of Babia Góra, avalanches are found to affect more than ⅓ of the length of the timberline, locally lowering it by as much as 350 m in distance. The timberline under the influence of avalanche processes is associated with steep slopes (>30°), with 90% of this being located on the massif's northern slope. In the long run (1964-2009), around the whole massif the timberline shows a high degree of stability along 79% of its length. It proved possible to reconstruct avalanche events along the largest avalanche path in the examined massif, the Szeroki Żleb gully. Nine such events are seen to have occurred over the past 120 years, with seven of these characterising the last 50 years. The avalanche(s) occurring in winter 1975/1976 had the greatest impact on the timberline in the Szeroki Żleb gully over the examined period.

Keywords

timberline • snow avalanche • Babia Góra Mountain • Norway spruce • image interpretation • dendrogeomorphology

Introduction

Extreme geomorphological events (snow avalanches, mudflows, debris flows, rock falls) are among the most important natural processes disrupting the course of the timberline around the world (Walsh et al. 1994; Kulakowski et al. 2006; Bebi et al. 2009). Debris flows and rock falls do not occur on the Babia Góra Mountain to such an extent as to modify the structure and position of the timberline. Indeed, from among the processes mentioned above, only avalanches occur at – and have a significant impact on – the ecotone of the timberline in this area (Łajczak 2005). In a classic high-mountain environment, the release avalanche zone starts in the morphogenetic periglacial (cryonival) system, with the avalanche itself here exerting a direct and indirect influence on the temperate forest system (Kotarba & Starkel 1972; Kotarba et al. 1987; Rączkowska 2007). The boundary between these two systems is determined by the timberline. The 'forest-avalanche' system is a bi-directional link - avalanches affect the structure and composition of the forest, and *vice versa*, in that the structure and composition of forest affect the dynamics, frequency and strength of avalanches (Brang et al. 2006; Kozłowska et al. 2006; Bebi et al. 2009; Czajka et al. 2012). In many mountainous areas, centuries of human intervention helped bring about a lowering of the timberline, even if this trend is now being reversed contemporarily. This change is connected with various forms of protection and climate change. As a result, the areas of release avalanche tracks are overgrown with forest or shrub vegetation (in the Carpathians mainly dwarf mountain pine), thereby reducing the size and impact of further avalanches (Plesník 1978; Czajka et al. 2012).

In the Polish Tatra Mountains, up to ⅓ of the timberline is affected by avalanche processes; with this value reaches 50% in some valleys (Dolina Roztoki in the High Tatra Mts.) (Czajka 2011; Kalafarski 2011). One of the indirect methods of studying the dynamics of extreme downslope mass movements is the multitemporal analysis of aerial and satellite images (Yarnold 1993; Evans et al. 2001). Studies of this type – in conjunction with work to date damage done to the trees growing within the impact of avalanches – allow for a reliable and detailed reconstruction of avalanche events (Stoffel & Bollschweiler 2009).

The aim of the study was to:

- identify the parts of the timberline on the Babia Góra Mt. that are affected directly by avalanches;
- determine changes that have taken place within this ecotone over the last 45 years;
- characterise the modern timberline ecotone, partly as contingent upon avalanche activity (TEa);
- determine the spatial and temporal dynamics to avalanche events in the Szeroki Żleb gully.

Study area

In the Polish Carpathians, a timberline under the influence of avalanches is present in the Tatra Mountains (Rysy - 2499 m a.s.l.), the Western Beskids (Babia Góra 1725 m a.s.l. and Pilsko 1557 m a.s.l.) and the Bieszczady Mountains (Tarnica 1346 m a.s.l.). In the extensive and high massif which is the Tatra Mountains (area ~ 785 km^2) about 40% of the avalanches reach the subalpine zone (Czajka 2010; Czajka et al. 2012). On the Babia Góra Mountain (area ~ 45 km^2), avalanches are common on the steep slope of northern exposure, and occasionally on the massif's southern slope. In many places they occur in the vicinity of tourist routes (the Szeroki Żleb gully, the Szeroki Upłaz gully or the path below the Brona Pass). They pose a threat to winter tourism, which involves about 20,000 tourists in the November-March period, with the total increasing year on year (Arcikiewicz 2009). This is a serious rationale for the systematic monitoring of avalanche events in the region.

The presence and duration of snow cover on the Babia Góra Mountain link up with local microclimate and microtopography. At the timberline altitude (1350-1400 m a.s.l.), on northern slopes in concave forms, it lasts 190 days per year (Obrębska-Starkel 2004). Snow cover persists from the end of October through to the end of May. The maximum snow depth near the timberline (150 cm on average) occurs mostly in March and can exceed 260 cm in the uppermost parts of the massif (Obrębska-Starklowa 1963).

The first information about avalanche events on the Babia Góra massif was presented by Midowicz (1930), who gave the names of six gullies down which avalanches might descend. The first research on the subject only dates back to the turn of the twentieth and twenty-first centuries (Łajczak 1995, 2004). To this day, the parts of the Polish Carpathians away from the Tatra Mountains (Kłapa 1959; Kłapowa 1969) have not been made subject to systematic monitoring of avalanche events. This denotes that the only communications on single avalanche descents are those

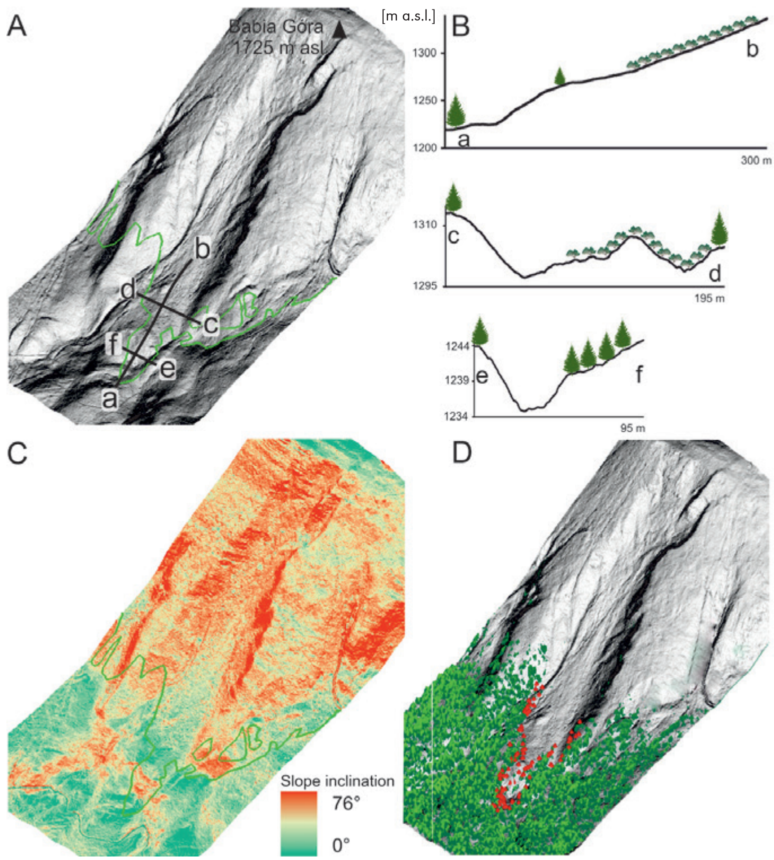


Figure 1. Physiogeographical characteristics of the avalanche in the Szeroki Żleb gully
Shaded relief of the study area with transverse and longitudinal profiles (A and B) and model of slope inclination (C). Spatial pattern of the subalpine forest around the gully (D) with sampled trees (red dots). The green line indicates the timberline

describing the Babia Góra region (Łajczak 2004; Midowicz 1992).

The area of the Szeroki Żleb gully, as the largest avalanche path on the massif, has been chosen for dendrochronological investigation. Its starting zone is very steep (slope 40°), and is located just below the main peak (~ 1720 m a.s.l.), with the avalanche track thus extending along a length of 850 m. Its maximum width reaches 350 m (Fig. 1A), while the depth may even be of 30 m. The timberline is lowered here by 300 m in altitude (to 1218 m a.s.l.) (Fig. 1B). In the runout zone a very steep ridge is found (40-45°) (Fig. 1C), and above this the bottom of the avalanche area is covered with dense dwarf mountain pine *Pinus mugo* scrub (at 1540-1280 m a.s.l.). Moreover, single spruce and mountain ash trees grow in the avalanche path. The eastern edges of the gully up to an altitude of 1315 m a.s.l. and the western edges up to 1350 m a.s.l. are covered with a dense and tall (~ 15 m) spruce forest (Fig. 1D).

Analysis of historical and current aerial photographs shows that, in the period 1964-2009, the timberline in the Szeroki Żleb gully lowered by ~80 m, with the bottom of the avalanche area now covered by young spruce forest (Fig.2). The literature makes no references to avalanche events during that time.

Figure 2. Spruce saplings in the runout zone of the avalanche's path

Methods and materials

Analyses carried out were based on two research methods: the interpretation of aerial images and dendrogeomorphology.

Image interpretation and GIS analysis

The long-term impact of the avalanche process on the timberline on the Babia Góra massif was examined by reference to compared orthophotomaps from 1964 and 2009 these being the earliest and latest available aerial photographs of the study area. In delineating the modern (2012) extent of forest cover, use was made of high-resolution measurement data deriving from Airborne Laser Scanning at a point density of 6 points per m^2. Sections of the timberline within which avalanches constitute the most important factor modelling the course were identified through field research (2011-2014), as well as reference to the literature (Zientarski 1985; Łajczak 1995, 2004) and cartographic materials, i.e. topographic maps (1:10,000) and geomorphological maps (1:5000; Łajczak, unpublished data). Inferred changes in the extent of forest cover were then categorized in terms of there being a stable, progressive or regressive timberline (cf. Czajka et al. 2015). These physiogeographical characterisations of the timberline ecotone were based on the digital representation of the terrain with a resolution of 0.5 m (as derived from the LiDAR point cloud). A Digital Elevation Model (DEM) and Digital Surface Model (DSM) were generated, with the latter normalised (nDSM) using by reference to the former. A slope inclination model (in degrees) and an aspect model were also elucidated.

A zone 15 m wide extending above and below the timberline was designated the timberline ecotone. The polygonal vector layer designated in this way was converted to a raster layer (of 1 m pixel size), before the the Combine tool was applied in assigning each pixel values for altitude, slope inclination, exposure and tree height (in relation to the contemporary course of the timberline). ESRI ArcMap 9.3 and 10.2.2 Software were used to analyse nearly 2 million pixels in total.

Abbreviations used in identifying individual areas of the timberline were: 15m-wide Timberline Ecotone on the Babia Góra Massif (TE); 15m-wide Timberline Ecotone affected by avalanches (TEa); 15-m-wide Timberline Ecotone affected by other factors (TEo)

Dendrogeomorphological analysis

A reconstruction of avalanche events in the Szeroki Żleb gully was attempted using dendrogeomorphological techniques. Snow avalanches moving with great force often carry with them, not only snow, but also rock and woody debris constituting an extra destructive force (Shroder 1978). Trees growing within the range of impact of an avalanche can suffer complete destruction or merely damage (to the trunk or branches, or in the form of decapitation) (Fig. 3) (Lundstrom et al. 2008). These types of damage are reflected as growth disturbances (GD) to the courses of annual tree-rings (Stoffel et al. 2005b). Damage to the trunk leave a permanent mark in the form of a scar overgrown with intact cambium from the side of the stem (Fig. 3A-1) (Sachs 1991; Larson 1994). At the same time, with a view to fungal infections being prevented, the tree produces large amounts of resin transported via the so-called traumatic resin ducts (TRD) (Fig. 3A-2) (Bannan 1936; Nagy et al. 2000; Bollschweiler et al. 2008). Another type of growth disorder is the strong 'growth suppression' (GS) often associated with decapitation, and reflecting the concentration in the apex of most of a given tree's auxin growth hormone (Friml 2003). The said 'growth suppression' caused in this way is both marked (≥ 60%) and prolonged (for ≥ 5 years) (Fig.3B-3) (Butler & Malanson 1985). Taken together, the tissues changes reflecting the overgrowth of an injury, TRDs and growth suppression represent a source of information through which avalanche events can be dated and reconstructed (Stoffel & Bollschweiler 2008).

The work described here entailed Pressler-bore sampling from Norway spruces (*Picea abies* L. Karst) and rowans (*Sorbus aucuparia* L.), the three cores taken from each specimen targeting the injury (sample X) and the TRDs (sample Y – spruces only), as well as serving as a reference (Z). Sampling extended to 110 trees in total, with each specimen being located to an accuracy of 1 m using Trimble Geoexplorer 6000 GPS (Fig. 3B).

Cores obtained were first polished to ensure a clear view of the growth rings, before being scanned at resolutions in the range 1200-3200 dpi. Digital images of growth-ring sequences were used in determining tree-ring

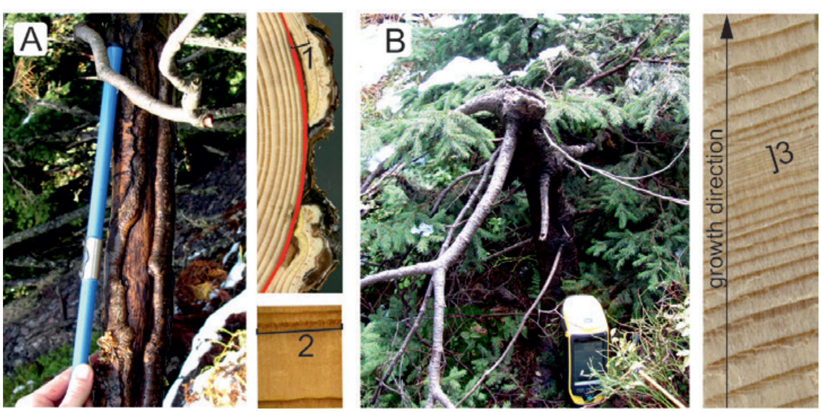


Figure 3. Trees injured during an avalanche event
Cross-section through an overgrowing injury on the tree trunk (A). Tissue overgrowing the injury (1) and traumatic resin ducts (TRD) (2). Red tree-ring represents year of event. A spruce with apex decapitation (B) which appeared by growth suppression (GS) (3)

width using *CooRecorder* software from *Cybis Elektronik* & *Data AB* (Larsson 2003a). The presence and nature of the traumatic resin ducts were examined under a microscope.

Crossdating of samples was a two-stage procedure first entailing work to detect possible missing rings through comparison of samples from an avalanche area with two (spruce and rowan) site chronologies specially constructed by reference to at least 30 undamaged trees. All Z samples were crossdated with the site chronologies using the *CDendro* program (*Cybis Elektronik & Data AB*) (Larsson 2003b). The tested Z samples constituted reference curves for the corresponding samples taken from the scars (X). Two sequences of growth rings were then isolated: an inner one consisting of rings from the pith to the injury and an outer one containing rings overgrowing the injury (Fig. 3A). These parts were dated separately in line with the high probability of their being separated by missing rings.

Should an avalanche occur in the winter of year A/B then by definition the ring for year A is complete (in that both early- and latewood is fully formed). Scars whose last tree-ring in the inner part are characterised by incomplete latewood were thus rejected from the analysis as not originating in a winter period and not therefore having been caused by the descent of an avalanche.

The dendrochronological reconstruction of avalanche events was based on:

- the dating of scars (T_i);
- the dating and characteristics of TRDs;
- GS dating associated with a scar or decapitation (T_{gs});
- the number of trees recording the same event (Rt) (Stoffel & Bollschweiler 2009), as compared with the number of living trees in a given year (At) and
- the spatial distribution of injured trees.

The main features determining TRDs are the intensity of their occurrence within the growth: strong (T_s), medium (T_m) or weak (T_w) (Schneuwly et al. 2009) and their position within the growth (Stoffel et al. 2005a).

Information items were used to calculate a modified weighted index (mW_{it}) (Kogelnig-Mayer et al. 2011). A dated scar in whose case the year of creation confirms the presence of TRDs (T_{i+TRD}) is the most reliable information about avalanche events.

$$mW_{it} = \Big(\big(T_{i+TRD} \cdot 6\big) + \big(T_i \cdot 5\big) + \big(T_s \cdot 3\big) + \big(T_m \cdot 2\big) + \big(T_w \cdot 1\big) + \big(T_{gs} \cdot 2\big)\Big) \cdot \left(\frac{\sum Rt}{\sum At} \cdot 100\%\right)$$

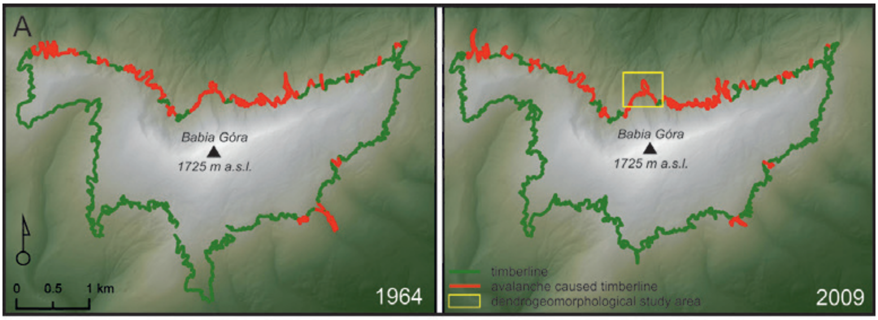
The threshold for the dated events was adopted for $mW_{it} \geq 0.5$, the existence of at least two GDs, among which at least one is a dated injury.

Spruce saplings growing at the bottom of the avalanche area were also sampled, with cores taken from trunks next to the ground to offer information on cambial age of use in dating the avalanche event lowering the Szeroki Żleb gully timberline post-1964.

Results

Timberline changes in relation to avalanche events

On the Babia Góra massif the contemporary timberline under the direct influence of avalanches is some 12.7 km long, which is to say that it constitutes 33% of the entire length of the timberline (Fig. 4). 65% of the regressive timberline is linked to avalanche events, which have mainly been confined to the northern slopes. There, the lowering of the timberline is of up to 350 m in distance. In turn, over the analysed 45-year period, the avalanche timberline (TEa) manifested no change over 79% of its length, with these stretches therefore definable as stable. The average altitude of the TEa in the 1960s was 1317 m a.s.l., as compared with 1322 m a.s.l. now. In comparison, the average altitude of the entire TE on the Babia Góra massif rose from 1354 m to 1370 m a.s.l. (Czajka et al. 2015). Individual avalanche paths are long, and descend deep into the forest; but they are also relatively narrow (20-100 m), with only two exceeding 100 m in width (maximum 350 m).



B

	Moment in time	Share of timberline lenght [%]	Max altitude [m a.s.l.]	Mean altitude [m a.s.l.]	Min altitude [m a.s.l.]	Mean slope inclination [deg]	Mean trees height [m]
AVALANCHE TIMBERLINE	1964	33.9	1452	1317	1140	29	
	2009	33.6	1466	1322	1106	30	12

Figure 4. The timberline on the Babia Góra massif modified by the avalanches of 1964 and 2009 Spatial distribution of the TEa (A) and its basic parameters (B)

Over 45 years, there have been changes of position along 20% of the overall length of the TEa. These changes are heterogeneous, in that there have been cases of both slight progress and slight regress of the TEa (by ~30 m). One of the avalanche gullies has ceased to be active and is completely overgrown with upper subalpine forest.

90% of the ecotone zone of the timberline modelled by avalanches (TEa) is present on the northern slope of the massif (with N, NW, NE exposures). Only 2% of the TEa coincides with slopes of southern or south-western exposure (Fig. 5A). Half of the TEa is on steep slopes (>30°). This is almost three times more than in the other parts of the TE (17%). Similarly, the average inclination of slopes occupied by the TEa is significantly greater (at 30°) than that characterising the TEo (22°) (Fig. 5C)

The area above the TEa is characterised by steeper slopes with an average inclination of 30°. As much as 55% of this is located on slopes with an inclination exceeding 30°. Very steep slopes, with an inclination of more than 40°, occupy only 7% of the TE, of which 70% is border affected by avalanche events (Fig. 6A).

The TEa is characterised by its being at lower altitudes than the TEo (Fig. 5B). The TEa is at its lowest average altitudes (1304 and 1308 m a.s.l.) on slopes of north-eastern and western exposure. Higher altitudes of the TEa are associated with south-western and southern exposures (1351 and 1377 m a.s.l. respectively). The slopes of these exposures are also the least steep ones (of average inclination 15° and 18° respectively) (Figs. 5C and 6B). There is an especially marked (50-56 m) difference in the average altitude above sea level between the surface of the TEa and the TEo on slopes of NW and W exposures.

On the less-steep slopes, the TEa runs at a slightly lower altitude that distinguishes it from the occurrence of the TEo; whereas on the overall massif flat ground is conducive to the growth and expansion of forest, with spruce forest present at still-higher altitudes (Fig. 6B). Moreover, on slopes with inclination of less than 15° there are far (up to 16 m) higher trees in the TEa than in parts of the TEo (13 m) (Fig. 6C). The average height of trees in the TEa zone is very similar to that of trees in the other parts of the TE (Fig. 5D).

Tall vegetation (of trees reaching more than 8 m in height) occupies 48% of the TEa, as compared with 40% in the case of the TEo. 50% of the zone above the timberline has low vegetation (<2m tall), while 35% has vegetation of medium (2-8 m) height. This compares with the zone above the TEo, in which the respective figures are 58% and 29% (Fig. 7).

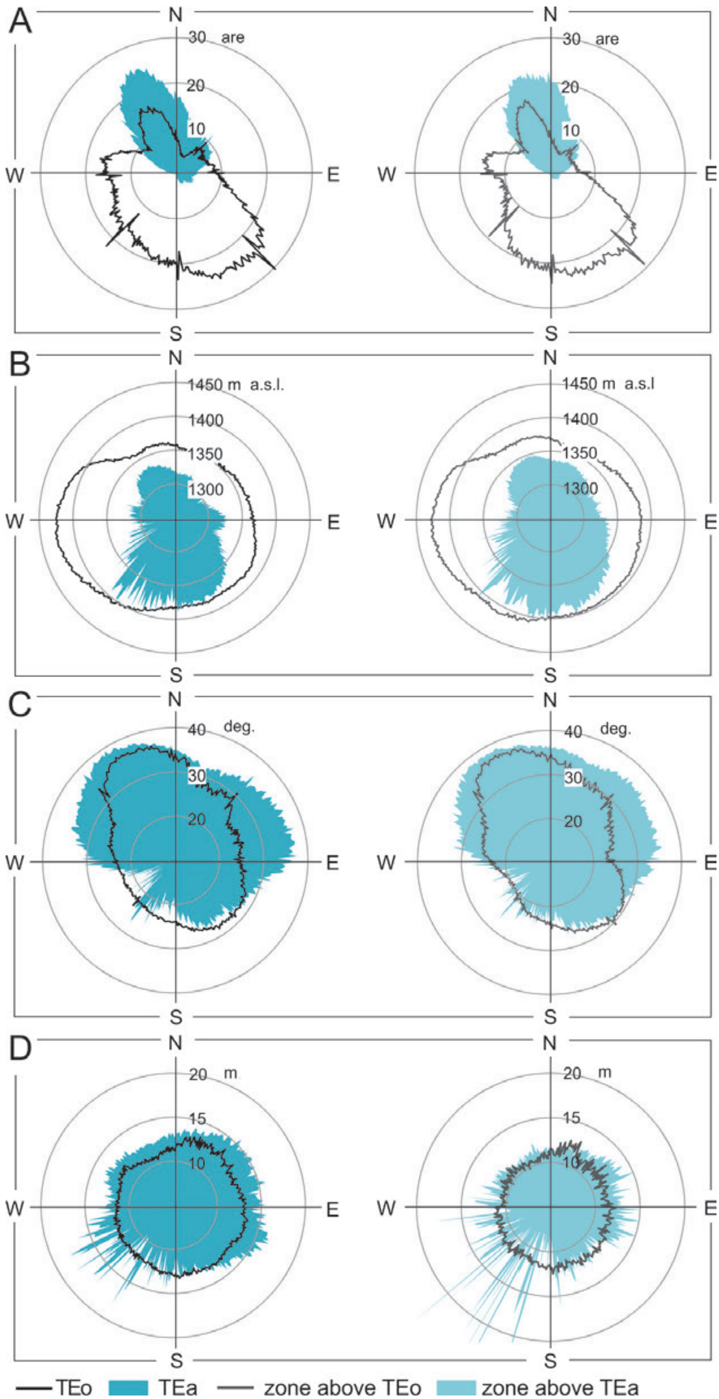


Figure 5. Characteristics of the timberline ecotone influenced by avalanches (TEa) in comparison with the other parts of the timberline (TEo), by reference to slope exposure:
A – ecotone area, B – average altitude, C – average slope inclination, D – average height of trees

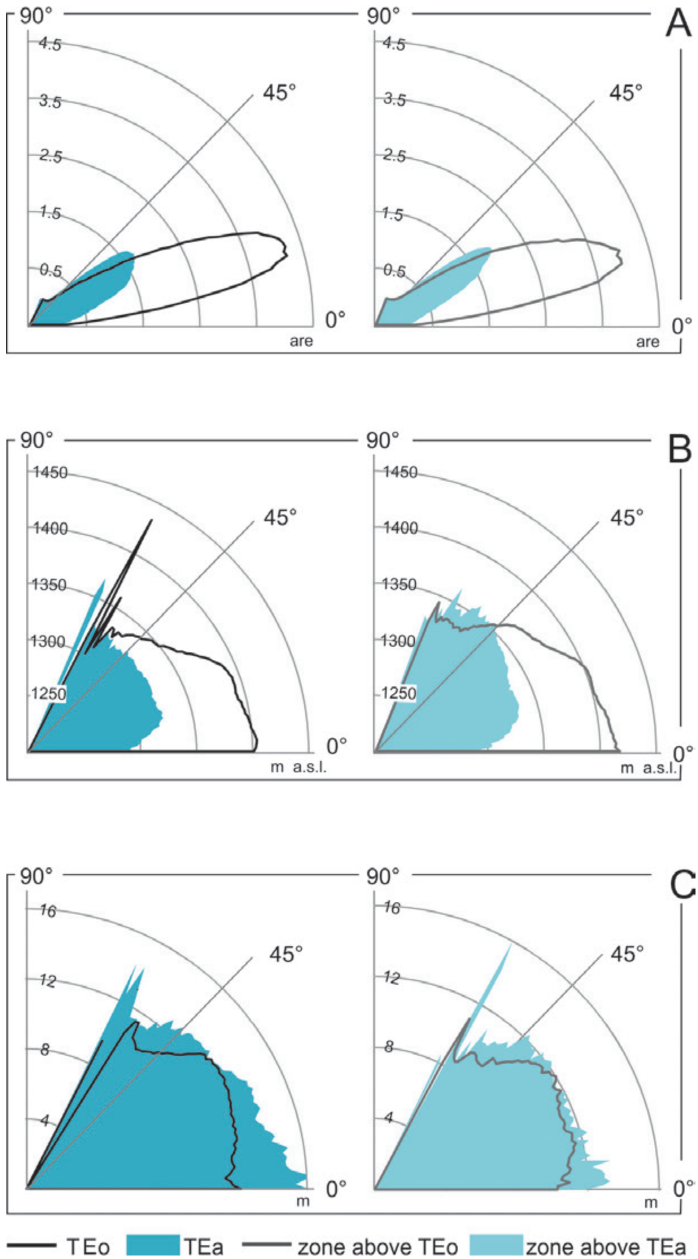


Figure 6. Characteristics of the timberline ecotone influenced by avalanches (TEa) in comparison with the other parts of the timberline (TEo), by reference to slope inclination:
A – ecotone area, B – average altitude, C – average height of trees

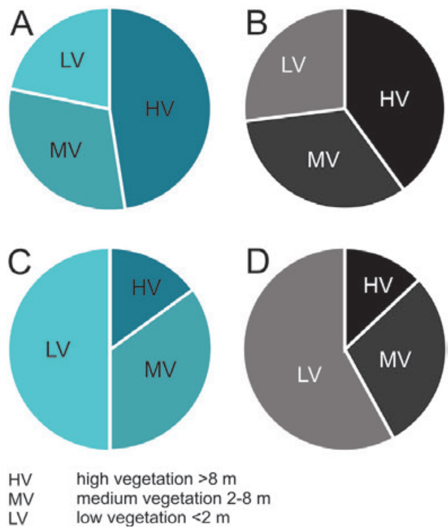


Figure 7. Land-cover structure in the area of the avalanche timberline (TEa) (A) as compared with other parts of the timberline (TEo) (B), and land-cover structure in the zone above TEa (C) and TEo (D).

Avalanche events in the Szeroki Żleb gully

227 cores from 110 damaged trees and 18 spruce saplings from the bottom of the avalanche area were examined. This material allowed for the analysis of 85 growth disturbances (GD). Of these, 34% reflect tree injuries (20% offering confirmed dating thanks to the presence of traumatic resin ducts), 59% the occurrence of traumatic resin ducts and the remaining 7% strong growth suppressions. The dating of individual GDs was carried out using two reference chronologies. In the case of spruce trees *Picea abies*, a 271-year chronology covering the period 1743-2013 and for rowans *Sorbus aucuparia* a 79-year chronology for the period 1935-2013. The average age of the examined trees from the avalanche path is 91 years in the case of spruce and 60 years in the case of rowan. The oldest examined tree is a 221-year-old spruce growing at the bottom of the avalanche area in its eastern part (Fig. 8B).

The reconstructed avalanche events in the examined gully are nine in number over the last 120 years (Fig. 8A). Most took place after 1960. Such a structure to the results is partly associated with the ages of trees. Trees more than 100 years old constitute 36% of the examined population (Fig. 8B).

The earliest events (from the winters of 1892/1893 and 1912/1913) were registered in injured trees growing at the bottom of the avalanche area (Fig. 8C). No avalanche events are capable of being inferred across the entire 50-year period between the winters of 1912/1913 and 1966/1967. In the case of the examined gully, avalanche events that are remembered on account of their intensity characterized winter 1975/1976 ($mW_{it} = 15.9$), at which time injuries were sustained by some 13 of the studied trees (27% of the living trees in the given year); as well as 1892/1893 ($mW_{it} = 2.2$), when 3 trees (20% of those living) were affected. The avalanche events of 1999/2000 and 2009/2010 affected only the uppermost part of the gully (Fig. 8C). Most (6 out of 9) avalanche events were recorded in trees growing in the bottleneck before the steep ridge.

Spruce saplings at the bottom of the avalanche area had already appeared 26 years ago (this being the age of the oldest of them) (Fig. 8D).

Discussion and conclusions

Avalanches are one of the most important factors influencing the timberline in the Babia Góra massif. They have exerted an impact along more than ⅓ of the entire length of the timberline, lowering it locally by as much as 350 m in distance. The paths taken by avalanches are much longer than they are wide, with the result that – notwithstanding the considerable number of events that have taken place (~43), only relatively small areas have been affected. The spatial impact is not in fact as major as the more extensive mountain ranges like the Western Tatra Mountains (Krzemień et al. 1995; Czajka 2010, 2011; Kalafarski 2011), in which avalanche paths extend over an average area of 230 acres. On Babia Góra only 5 avalanche paths attained such dimensions.

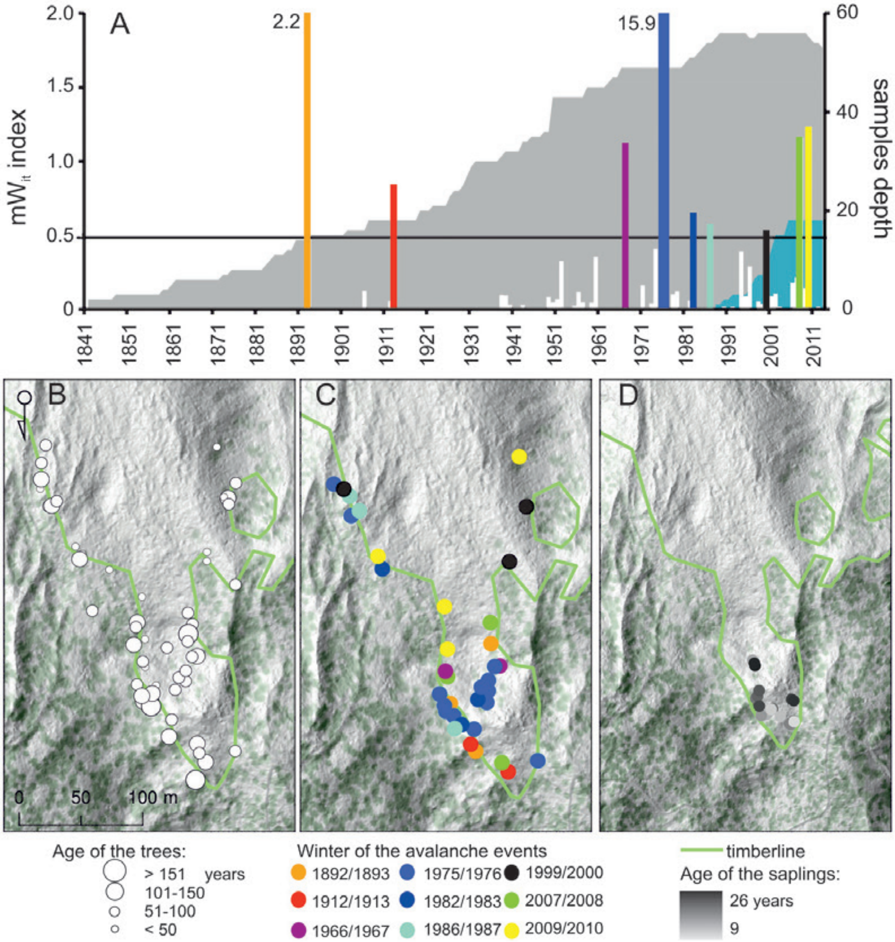


Figure 8. A spatial and temporal reconstruction of the avalanche events in the Szeroki Żleb gully Dated tree injuries on the timeline (A). Colourful columns correspond to dated events that exceed the index threshold (mWit ≥0.5). Grey area indicates number of sampled trees. Spatial distribution of trees depending on: tree age (B), recorded avalanche events (C) and spruce-sapling age structure (D)

The stretch of timberline under the influence of avalanche processes is associated with steep slopes (> 30°), while 90% of it is located on the northern slope of the massif. This is determined by the characteristic relief of the massif (Łajczak 2005; Czajka et al. 2015). A typical feature is the presence of a timberline lower down on the less-steep slopes and in the form of a forest made up of tall trees. The ecotone of the avalanche timberline (TEa) has a greater share of tall vegetation in the land-cover structure (accounting for 48%) than is the case for other parts of the timberline (40%). This dependence can be explained by the fact that the final runout zones are less steep and are located further into the upper subalpine zone, in which trees grow in less-extreme climatic conditions and attain greater dimensions. On the other hand, the zone above the TEa is covered with medium-height vegetation (35%, mainly of dwarf mountain pine *Pinus mugo*) to a greater degree than other parts of the timberline (29%). The height of the trees along the massif does not change significantly depending on the type of timberline. The steep northern slopes of the massif covered with avalanche gullies have not been used in pastoralism, or exploited in any other way. For this reason, a large part of the area above 1250 m – including the timberline ecotone and the scrub of dwarf mountain pine – has retained its natural character.

The degree of avalanche stability and dynamics of the timberline on the Babia Góra massif are dependent on the temporal and spatial scales adopted for study. Single avalanche events have a marked impact on the course and character of the timberline along a given path. Such events are separated by periods of re-overgrowth of the avalanche path with forest or dwarf mountain pine scrub. In the long run (1964-2009) and over the massif as a whole, the course of the timberline has manifested a high degree of stability along 79% of its length. The results of similar research conducted in the Tatra Mountains (Czajka et al. 2012) show a clear difference between the TEa in these two mountainous areas in close proximity to one another. Most of the avalanche paths reaching the timberline in the Tatra Mts. have been reduced and narrowed over the last 60 years – a phenomenon perhaps connected with human activity (Czajka et al. 2012). Research from the Swiss and French Alps (Martin et al. 2001; Laternser & Schneebeli 2002; Eckert et al. 2010) in turn suggests that recent climate change has had no apparent influence on avalanche fluctuations over the last 50-60 years.

Through the use of dendrogeomorphological techniques, it proved possible to reconstruct avalanche events along the most extensive avalanche path in the examined massif, the Szeroki Żleb gully. Over a 120-year period, this gully was affected by nine avalanche events (in the winters of 1892/1893, 1912/1913, 1966/1967, 1975/1976, 1982/1983, 1986/1987, 1999/2000, 2007/2008, 2009/2010). It is notable that seven of these have occurred within the last half-century. The spatial distribution of damaged trees makes it clear that avalanches in the Szeroki Żleb gully impact most upon the timberline where the gully narrows just above the steep ridge (it was here that growing trees registered the greatest number of avalanche events). The avalanches in the years 1999/2000 and 2009/2010 were more minor, and extended over a more limited area, as they are only reflected in the growth of spruces in the upper part of the gully. By contrast, the avalanche(s) that occurred in winter 1975/1976 had the greatest impact on the timberline in the Szeroki Żleb gully of any in the examined period, affecting almost ⅓ of the trees growing on the edge of the avalanche area.

The Babia Góra massif lacks an avalanche monitoring system, and nor is avalanche research conducted on any larger scale. This ensures a lack of more precise information on avalanche descents. Midowicz (1992) reports briefly on four: an event on the northern slopes under Sokolica in winter (1922) one in the Piarżysty Żleb gully (1977), one under Szeroki Upłaz along the Cylowy Potok stream (1987), and one under Kościółki (1987). The possibility of avalanche events in the Szeroki Żleb gully is also raised.

On the massif under examination a state of equilibrium has developed between the upper subalpine forest and avalanche events. With a limited human impact, the environment does not change much in terms of quality and quantity. This is another factor attesting to the ecological control of the timberline on the northern slope of Babia Góra (Balon 2007).

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Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors' on the basis of their own research.

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