Chapter

Impacts of Human Activities on the High Mountain Landscape of the Tatras (Example of the Border Area of the High and Belianske Tatras, Slovakia)

Veronika Piscová, Juraj Hreško, Michal Ševčík and Terézia Slobodová

Abstract

We summarize impacts of human activities on the alpine landscape at the border of the High and Belianske Tatras (Slovakia). The High Tatras, especially due to the glacial relief on the crystalline rocks and specific climatic conditions, represent the most attractive area of year-round tourism. The Belianske Tatras represent the limestone part of the mountain range, with rare communities, many endemics and glacial relics, and are among the rarest and most endangered mountains in Slovakia. In the past, this area was mainly affected by grazing, forest cutting and mining. Currently, the area is protected as the Tatra National Park, the Tatras Biosphere Reserve, by the Habitats Directive and the Birds Directive, tourism is the only human activity in the area. Due to tourism, the ridge trail of the Belianske Tatras has been closed since 1978 and one of the trails has been open since 1993. The current hiking, as the only activity in the area, is bearable, which was confirmed by experimental research. But hiking trails are threatened by many morphodynamic processes.

Keywords: high mountain landscape, the Tatras, land use change, human effects, trampling, synanthropisation, hiking trail

1. Introduction

The mountains are vital to life on Earth. Approximately 27% of the Earth's surface (40 million km^2) are covered by mountains [1], which possess at least one third of the species of the entire species diversity of terrestrial plants [2] and, at the same time, supply half of the human population with water [3, 4]. In the course of natural development, high mountains have become a refuge of many rare, endangered and endemic species and habitats [5]. Plant communities, differentiated both by height and species, very effectively capture water precipitation, snow, fog and ice. They regulate their runoff, allow uniform distribution of moisture throughout the soil horizon profile, and ensure a long-term balanced water regime [3]. For these reasons, plant communities in high altitudes have an irreplaceable role. These are mainly spring areas of watercourses, which are currently the last surface sources of clean water [4].

The alpine landscape in particular represents a unique biogeographical unit of the Earth. The territory covered by alpine vegetation is fragmented into several mountain regions [6, 7]. Alpine landscape can be found at all latitudes [8, 9]. It occupies 4 million km^2, which represents almost 3% of the Earth's land surface. Alpine vegetation hides a great variety of species around the world, including 8,000–10,000 species of vascular plants. Alpine ecosystems have a strong impact on humans. Around 10% of the world's population lives in high-altitude regions, and more than 40% of them depend in some way on the resources of these ecosystems, in particular drinking and irrigation water from high altitude basins [9].

The alpine landscape of Slovakia is understood as mountains with developed upper forest boundaries and higher vegetation zones: subalpine, alpine and subnival [10]. The subalpine vegetation zone follows the montane vegetation zone and ends with an upper limit of the continuous occurrence of shrubland at an altitude of approximately 1850 m above sea level. [11]. The alpine zone follows the subalpine zone and extends to a height of about 2300 m above sea level. It consists of original, primary alpine meadows, which extend over the shrubland zone, the so-called alpine grasslands. The subnival zone is the highest vegetation zone of the Tatras at altitudes from 2300 m to the highest peaks. The vegetation is poor, more continuous vegetation cover does not exist, plants occupy rock cracks, walls and slits. In Slovakia, the alpine landscape occupies 320 km^2, which represents 0.7% of the country's territory [12]. The island character of the high mountains, their height and substratum ruggedness created suitable conditions for the creation of a varied mosaic of vegetation types with a number of naturally rare, relict and endemic plants. The Alpine landscape in Slovakia is found only in national parks, which mainly protect their ecosystems.

The unique alpine landscape with which humans have been connected since the past is represented by the smallest high mountains in the world, the Tatra Mountains. In the past, in the places where now exist the highest peaks, prehistoric seas were spreading, massive layers of sediments were deposited, mountain-forming processes were taking place and prehistoric animals were moving around the landscape. Today's appearance of the Tatras has been completed by processes in the last two million years. Mountain massifs elevated by alpine folding with remains of layers of sedimentary rocks formed mountain glaciers during probably four ice ages. They pushed huge volumes of rubble out of them and gave them the character of high mountains. The alternation of hot and cold periods, dry and humid periods in the Holocene was the key to the development of today's plant and animal kingdom. In the 11th century, they were surrounded by one large primary forest, and until the 14th century only isolated shepherds, treasure hunters and lumberjacks wandered into their valleys. Major changes occurred in the 14th – 17th centuries, when Wallachian colonization was directed to higher mountain areas. In the 18th – 19th centuries, most of the accessible forests were grubbed up for the needs of mining, metallurgy and construction. Following the shepherds and lumberjacks came researchers, tourists and climbers [13].

People perceived the rare beauty of the mountains and their uniqueness in the distant past. In order to preserve them, they declared the first protected areas. The aim was protection of their beauty, protection for religious and utilitarian reasons and protection of wildlife with original game for hunting. Later, biological, biogeographical and ecological aspects were pushed to the fore, such as protection of rare and endangered species and their habitats, protection of representative ecosystems, up to the systemically understood protection of natural ecosystems and original ecological processes [14].

However, a question has been hanging over national parks since the creation of the first ones – how to preserve the original nature from the emerging anthropic pressure and, at the same time, how to make the national park available for recreation and relaxation? This is a global issue applying to national parks around the world [14]. Protected areas are now considered as effective and promising instruments not only of a global strategy, but also of national strategies aimed at combating biodiversity loss [15, 16]. The mission of nature conservation areas is to preserve biodiversity and functioning natural ecosystems that serve as a refuge for many endangered plant and animal species and provide ecosystem services. However, they are often disturbed in most of the area of the intensively used landscape that surrounds them [14–16]. Despite great efforts to preserve the nature of the mountains, there are still significant changes in the environment. These changes are the result of climate change, deforestation or natural disasters, in many places in less developed countries in the world, also of mineral extraction, armed conflicts, poverty and hunger. In more advanced countries, as a result of modern times that have brought about the development of sports facilities, recreation and tourism, new roads, hotels and lifts have been built. This is a global trend. More than 50 million people visit mountains every year [17]. Many mountain towns around the world depend on the development of tourism. Catering and accommodation services for tourists who come to admire the mountains are developed in the villages.

The Tatras, despite their protection, they are threatened by an increasing number of tourists and increasing demands for the construction of infrastructure connected with services. In this chapter, we focus on the area located on the border of the High and Belianske Tatras, where the alpine landscape is characterized by various degrees of destruction, but, at the same time, almost undisturbed unique nature. We focus on the impacts of human activities on the high mountain landscape during the past and at present.

2. The border area of the High and Belianske Tatras (Slovakia)

The area of interest represents the border area between the High Tatras and the Belianske Tatras (**Figure 1**), which are parts of the Tatra Mountains. We chose it because of its rarity and uniqueness, but also because of the damage caused by human activities during the past and at present.

2.1 Characteristics of the area

The Tatra Mountains belong to the Alpine and Himalayan system and are a part of the extensive range of the Carpathian Mountains, spreading over the territories of Austria, the Czech Republic, Slovakia, Hungary, Poland, Ukraine, Romania and Serbia. The entire mountain range covers approximately 210,000 km^2, the length of the Carpathian arch reaches 1,500 km, the width ranges from approximately 12 to 350 km [18]. The highest part of the Carpathians are the Tatras, namely the High Tatras and Gerlachovský Peak with an altitude of 2654 m, which is their highest peak. Within the Carpathians, the study area belongs to the extensive mountain province of

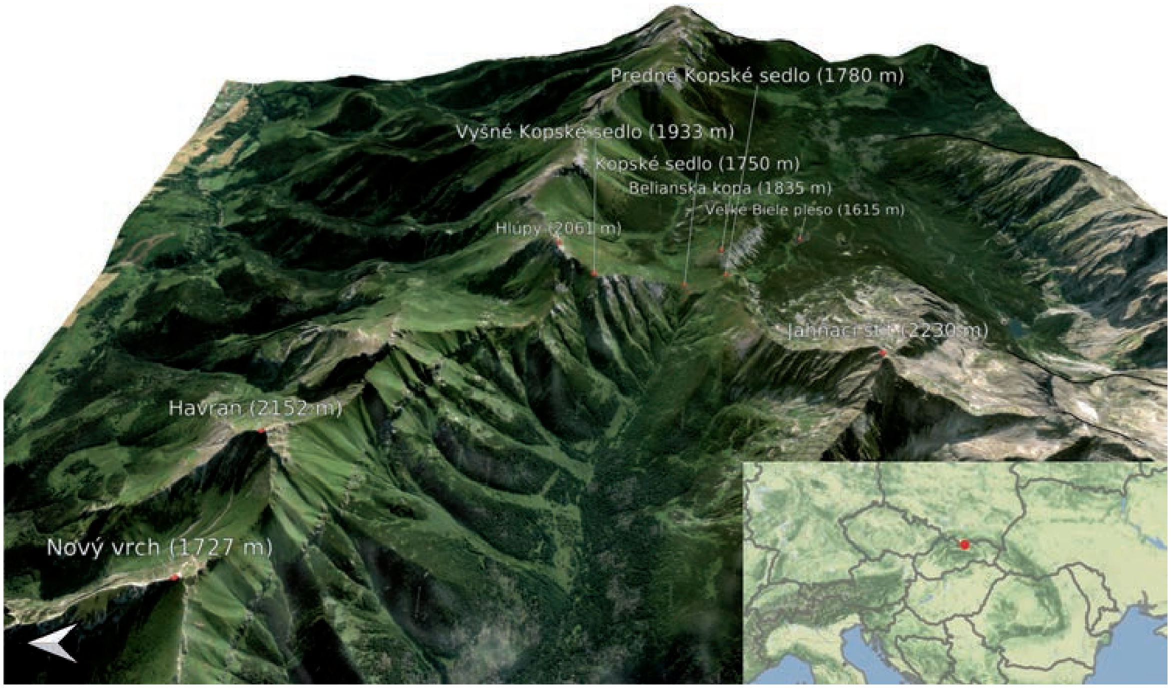

Figure 1.
Study area (Source: mapy.cz).

Figure 2.
The High Tatras – the tarn Veľké Biele pleso (1615 m MSL) (Piscová, 2021).

the Western Carpathians, situated in the western part of the Carpathian Mountains. The arc of the Western Carpathians extends to the territories of the Czech Republic (namely Moravia and Silesia), Slovakia, Poland (smaller northern part), Hungary (south-eastern part) and Austria (south-western parts). The total area of the Western Carpathians is about 70,000 km^2, the length of the mountains reaches 400 km. The course of the narrow Pieniny Klippen Belt divides the Western Carpathians into external and internal, which differ significantly in their geological history, geological composition and tectonic development [19].

The Tatras are considered to be a model of a high mountain range, because all typical alpine features can be found here in a relatively small area [20]. The environment which prevailed in the Tatras in the last Ice Age significantly marked the ductility of their surface. The relatively short warmer period of the Holocene (Ice Age, the younger Quarternary) was not enough to reshape these older forms of relief [21]. The High Tatras (**Figure 2 amd 3**) are the highest mountain range of the Western Carpathians, formed by glacial activity. The Belianske Tatras (**Figure 4**) are considerably smaller than the High Tatras, it is the highest carbonate mountain range of the Western Carpathians, thanks to its Mesozoic sediments characterized by a characteristic gradation of mountain massifs [22].

Climatically, the Tatras fall into a cold area with a predominantly cold and cold mountain district. The area of the upper limit of the forest is characterized by an average annual air temperature of 2–4°C, an average July temperature of 10–12°C and an average annual rainfall of 900–1,200 mm. Above the border of the forest, the temperatures are even lower and precipitation is higher [23].

Figure 3.
The High Tatras, the summit Belianska kopa (1835 m MSL) (Hreško, 2005).

Figure 4.
The Belianske Tatras (Hreško, 2005).

A general characteristic of the soils of the High Tatras is an acidic to very acidic soil reaction. In the Alpine landscape of the Tatras we can find the following soil types: lithosols, rankers, rendzinas, cambisols and podsols [24].

There are two national parks in the whole territory of the Tatras: in the territory of Slovakia the Tatra National Park (TANAP), declared in 1948 with effect from 1 January 1949, with an area of 1,045 km^2 (of which the national park's own territory has 738 km^2, national park protection zone 307 km^2), and in Poland Tatrzański Park Narodowy, declared in 1954 with effect from 1 January 1955, with an area of 212 km^2. TANAP is the first and therefore the oldest national park in Slovakia. It was established by the Slovak National Council law No. 11/1948 Coll. on the Tatra National Park [25]. Its protection is currently provided for by Legislative Act No. 543/2002 Coll. on Nature and Landscape Protection [26], as amended.

Biosphere reserve Tatry (BR Tatras) entered into the world network of biosphere reserves on 15th February 1993 with an area of 113,251 ha. It is a bilateral biosphere reserve, which includes TANAP and its buffer zone (on the territory of the Slovak Republic) and Tatrzański Park Narodowy TPN (on the territory of Poland).

In addition to the protected areas at national level, the territory of the Tatras is also defined according to European legislation, in order to preserve the natural heritage important not only for the member state, but for the entire EU. These are the two directives: (1) Council Directive of the European Communities No. 79/409/EEC on the conservation of wild birds (Birds Directive) [27] and (2) Council Directive No. 92/43/EEC on the conservation of habitats and of wild fauna and flora (Habitats Directive) [28]. The Natura 2000 network consists of two types of areas: areas of European importance and protected bird areas. The area of European importance for Slovakia is defined by the Decree of the Ministry of Environment of the Slovak Republic No. 3/2004–5.1 of 14 July 2004 [29], which issues a national list of areas of European importance, and the protected bird area is established by the Decree of the Ministry of Environment No. 4/2011 Coll. [30], which declares the Protected Bird Area of the Tatras.

The studied area represents the boundary area of two geologically and geomorphologically distinct parts of the Tatras. The High Tatras, mainly due to its glacial relief, rock composition and specific climatic conditions, represent the most attractive area of year-round tourism. The Belianske Tatras represent one of the highest limestone mountains in Slovakia. With its habitats of rare communities and a number of endemics and glacial relics they are among the rarest and most endangered mountains in Slovakia. The studied area is located in the national nature reserve Belianske Tatras, which was declared to protect a territory with a great variety of species (even rare and endemic) and communities of fauna and flora, to protect the richness of glacial forms of relief on granites and mylonites as these geosystems are very unstable. In the past, especially due to the unbearably high number of visitors of this area, the rare ecosystems of the Belianske Tatras were damaged. In the study area, grazing, mining activities, general removal of shrubland and later unbearable hiking were taking place. The Belianske Tatras ridge trail has been closed to tourists since 1978. Since 1993, a part of the Monkova dolina valley has been accessible in one direction, since 2009 in two directions.

2.2 Rare ecosystems with many endemic and glacial relics

The Belianske Tatras represent one of the highest limestone mountains in Slovakia, with its habitats with rare communities and a number of endemics and glacial relics are among the rarest and most endangered mountains in Slovakia. The studied area is located in the Belianske Tatry National Natural Preserve (NNP), which was declared in 1991 by the Decree of the Slovak Commission for the Environment No. 166/1991 Coll. of 15.1.1991 on the State Nature Reserves and the Protected Sites in the TANAP [31]. The subject of NNP protection are habitats with rare communities and a number of endemics and glacial relics and the richness of glacial forms of relief on granites and mylonites, which are very unstable.

2.2.1 Development of vegetation since the last glaciation, current endemics and relics

After the retreat of glaciers, deep glacial valleys, morenas, lakes, rocky ridges with many peaks, towers and needles interwoven with tight saddles were created in the Tatras. After the end of the Ice Age (plesitocene), i.e. approximately 12,000 years ago, the vegetation of the Tatras began to form. On the outskirts of the Tatras, the vegetation in the glacier neighborhood had a tundra character with species of bush-like growth, such as *Dryas octopetala* (**Figure 5**) and *Salix reticulata* (**Figure 6**), which grow here to this day. Scattered tree vegetation consisted of shrub, pinus cembra, spruce, larch and birch [21].

In the preboreal (8300–6800 BC), the climate was colder on average by about 5°C than today and in the Tatras there was a dramatic change in the representation of tree and non-tree vegetation. Its ratio changed from 1:1 to 10:1. The upper limit of the forest was at a height of about 90–1000 m MSL, in addition to spruce it consisted of smaller areas of shrubs and stunted birch. Areas above 2000 m MSL were still covered by permanent snow and ice. In the boreal (6800–5500 BC), the average temperature increased by about 2°C more than at present. The upper limit of the forest was pushed to a height of 1700 m. In the forests predominated spruce, pine, fir, and towards the end of the period larches and broadleaves (lime, oak, birch). The Atlantic (5500–2500 BC) was a period with a relatively humid and warm climate, the temperature was higher by 3°C than today, precipitation was 60–70% more abudndant. The upper limit of the forest in the Tatras consisted of continuous pine-spruce forests with representation of larch and fir. On the southern side of the Tatras it reached a height of 1800 m MSL and on the northern side up to 1700 m MSL. Above the spruce stage, a strip of shrubland extending up to 2200 m MSL was formed. The pine remained more continuous only in cliff habitats. In the Subboreal (2500–800 BC), the temperature was slightly higher than it is now, but the air was drier, especially towards the end of

Figure 5.
Dryas octopetala (Piscová, 2008).

this period. In this period, we can assume the development of spruce forests, at lower altitudes beech and fir were also more abundantly represented. In mixed oak forests, oak prevailed over other plants, while elms almost disappeared completely. At the end of the Subboreal roughly the same zoning of vegetation with regard to the altitude that still exists today was formed. At the beginning of the Subatlantic (750 BC to the present day), the climate partially cooled down and was perhaps colder than it is today. The upper limit of the forest was lowered and vegetation elevational zones were stabilised as we know them today [21].

During the development of vegetation, the Tatras and their parts have become a specific territory for the occurrence of many endemics. Species such *Pinus cembra*, *Gentiana nivalis*, *Erigeron uniflorus*, *Carex lachenalii*, *Saussurea pygmaea*, *Artemisia eriantha* and *Ranunculus thora* [32] and a west-carpathian element *Luzula alpinopilosa* subsp. *obscura* [33] grow only in the Tatras. Only in the High Tatras there is *Cerastium uniflorum*, *Ranunculus pygmaeus*, *Ranunculus reptans*, *Armeria alpina* and *Juncus castaneus* [33]. Many species are found only in the Belianske Tatras [33], e.g., *Draba siliquosa*, *Draba fladnizensis*, *Draba pacheri*, *Petrocallis pyrenaica*, *Arctous alpina*, *Juncus triglumis*, *Kobresia simpliciuscula*, *Bellardiochloa variegata*, *Tofieldia pusilla*, *Carex atrofusca*. Glacial relics (remnants of the Ice Age) are represented by the species of *Dryas octopetala*, *Arctous alpina*, *Ranunculus reptans* [34]. Frequent fogs and a large amount of precipitation cause the occurrence of moist and humicolous species also in places that are exposed with occurrence of strong winds (*Arctous alpina*, *Carex atrofusca*, *Juncus triglumis*, *Pritzelago alpina*, *Pyrola carpatica*, *Saxifraga wahlenbergii*, *Tofieldia pusilla*), some of which in the Western Carpathians represent extremely rare postglacial relics.

Figure 6.
Salix reticulata (Piscová, 2008).

Several different plant growth forms have adapted to grow and reproduce under harsh environmental conditions [9, 35, 36]. As the altitude increases, the temperature decreases, the length of the vegetation season decreases and precipitation and humidity increase, which also causes the composition of the flora to change. These rare cushion-forming plants are one of the most conspicuous plants found in the most exposed alpine habitats [7]. Due to their low stature and compact form, cushion plants can modify environmental conditions creating particular microclimates within their canopies [9, 37], cushions are maintaining higher temperatures than their surrounding environment [38], reduce the wind speed by up to 90% [39], create their own humus and the diversity in the cushions is higher by 30–50% [37, 40–45], suggesting that cushions may influence the survival of other species [38]. Cushion plants also occur in the study area (**Figures 7** and **8**). The cushion plant form is not endemic to any single area or plant family. Cushion plants grow very slowly, with this inhibited growth there is increased longevity, with the largest cushions of some species reaching ages of up to 350–3000 years [46, 47].

2.2.2 Rare Communities of Plants

The alpine plant communities on the limestone subsoil of the Belianske and parts of the High Tatras with tourist trails are floristically extremely rich [48]. Their nomenclature is given in accordance with the work [49]. The surroundings of the trail leading from Tatranská Javorina (1000 m MSL) to Kopské sedlo (1750 m MSL) are lined with communities *Phleo alpini-Deschampsietum caespitosae* Krajina 1933)

Figure 7.
Cushion plants on the Hlúpy vrch (2061 m MSL) (Piscová, 2011).

Figure 8.
Cushion plants (Piscová, 2011).

Coldea 1983 (1424 m MSL)*Rhodiolo-Deschampsietum caespitosae* Krajina 1933 a *Vaccinio myrtilli-Calamagrostietum villosae* Sillinger 1933 (1450 m MSL); furthermore with the high-stem community*Geranio sylvatici-Calamagrostietum variae* (Sillinger 1932) Kliment et al. 2004 (1458 m MSL); the grass-herbal association *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek (1508 m MSL) the community *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek in which two other types of associations occurr, *Seslerietum tatrae* a *Rhodiolo-Deschampsietum caespitosae* Krajina 1933 (1642 m MSL). At an altitude of 1698 m MSL, we recorded a mosaic of communities *Festuco picturatae-Calamagrostietum villosae crepidetosum conyzifoliae*, *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005, *Arenario tenellae-Caricetum firmae* (Br.-Bl. 1930) Šibík et al. 2004 and *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek. In Kopské sedlo there is a community *Juncetum trifidi* Krajina 1933.

The trail leading from the Veľké Biele pleso (1615 m MSL) to the Kopské sedlo (1750 m MSL) is lined by communities *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek nom. and *Festuco picturatae-Calamagrostietum villosae* Pawłowski in Pawłowski et al. 1928 corr. Kliment et al. 2004, at an altitude of 1642 m MSL communities of *Festuco picturatae-Calamagrostietum villosae* Pawłowski in Pawłowski et al. 1928 corr. Kliment et al. 2004,*Junco trifidi-Festucetum supinae* Krajina 1933 and *Festuco picturatae-Calamagrostietum villosae* Pawłowski in Pawłowski et al. 1928 corr. Kliment et al. 2004, then *Junco trifidi-Festucetum supinae* Krajina 1933 and *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek nom. (1777 m MSL), in the Predné Kopské sedlo the community *Junco trifidi-Callunetum vulgaris* (Krajina 1933) Hatcher ex Šibík et al. 2007 (1778 m MSL) and the section between the Predné Kopské sedlo and Zadné Kopské sedlo is lined by communities *Juncetum trifidi* Krajina 1933 and *Rhodiolo-Deschampsietum caespitosae* Krajina 1933.

The hiking trail leading from the Široké sedlo (1825 m MSL) to the Kopské sedlo (1750 m MSL) passes through the communities *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek nom., *Rhodiolo-Deschampsietum caespitosae* Krajina 1933 and *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005, then at an altitude of 1831–1907 m MSL by the community *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005. and at the altitude of 1919 m MSL passes through the arcto-alpine community of strongly blown ridges and edges, the association *Drabo siliquosae-Festucetum versicoloris* Petrík in Petrík et al. 2006 and the association *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005. The trail continues through the community *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek and at an altitude of 1927 m MSL, the community *Ranunculo pseudomontani-Caricetum sempervirentis*, however, this community is accompanied by association species *Seslerietum tatrae* Domin. 1929 corr. Kliment et al. 2005. From Vyšné Kopské sedlo (1933 m MSL) the trail continues to fall and passes through *the communities of Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek and *Seslerietum tatrae* Domin. 1929 corr. Kliment et al. 2005 (1907 MSL), then a mosaic of communities *Junco trifidi-Festucetum supinae* Krajina 1933, *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005 and *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek (1826 m MSL), which extend up to Kopské sedlo (1750 m MSL).

The closed trail leading from the Široké sedlo (1825 m MSL) to the Ždiarska vidla (2142 m MSL) is lined near the saddle by communities *Seslerietum tatrae* Domin 1929 corr. Kliment et al. 2005, *Junco trifidi-Festucetum supinae* Krajina 1933 and *Ranunculo pseudomontani-Caricetum sempervirentis* (Krajina 1933) Dúbravcová ex Dúbravcová et Jarolímek (2025 m MSL).

The closed trail leading from Vyšné Kopské sedlo (1933 m MSL) through a part of the Belianske Tatras, Front Medďodoly is lined near the saddle by the community *Festuco versicoloris-Oreochloetum distichae* Pawłowski et Stecki 1927 corr. Petrík et al. 2006 nom. Invers. propos. (2018 m MSL).

Only in the ridge positions of the Belianske Tatras are there Central European relic communities of strongly blown ridges and edges of the alpine to subnival zone *Oxytropido-Elynetalia* Oberdorfer ex Albrecht 1969 on strongly blown ridges and edges on neutral to slightly base substrates in the alpine zone. These are rare communities not only because of their limited occurrence, but mainly because of their floristic composition with a large number of Arctic-Alpine species. There are also Alpine grassy, cushion and shrubby communities of rock walls and fine skeletal rubble on mylonites in the alpine to subnival zones *Festucion versicoloris* Krajina 1933. These are the communities threatened all year round by alpine tourism. Rare is the occurrence of the species *Carex rupestris*, which more rarely penetrates the vegetation in the ridge part of the Belianske Tatras, into the union *Caricion firmae*. The main ridge of the Belianske Tatras (from Ždiarská Vidla to Predné Jatky) is also covered by the occurrence of the species *Elyna myosuroides*. An open, floristically rich community *Oxytropido carpaticae-Elynetum myosuroides* (Puşcaru et al. 1956) Coldea 1991 usually inhabits rocky edges or rock terraces. In the community *Drabo siliquosae-Festucetum versicoloris* Petrík in Petrík et al. 2006, there are a number of rare and phyto-geographically significant species such as *Bellardiochloa violacea*, *Draba fladnizensis*, *D. siliquosa*. Plants *Pyrolo carpaticae-Salicetum reticulatae* Petrík in Petrík et al. 2006 by their character represent the Arctic-Alpine tundra. On the wind-blown flat, only slightly inclined, sometimes almost flat places in ridge, less often in sub-ridge positions occurs the cushion-turf community *Festuco versicoloris-Oreochloetum distichae* Pawłowski et Stecki 1927 corr. Petrík et al. 2006 nom. Invers. propos. (2018 m MSL). The community *Silenetum acaulis* Country 1933 developed in the most extreme alpine locations where survival conditions are very limited. Growths of *Agrostio alpinae-Festucetum versicoloris* Pawłowski in Pawłowski et al. 1928 nom. Invers. propos. Inhabit terraces of almost vertical rock walls and rock ribs. The rubble habitats under the steep rock walls are inhabited by the communities of *Salicetum kitaibelianae* Krajina 1933.

2.2.3 The rarest animals living in the territory, endemic

The current state of animal distribution in the territory of the Tatra National Park is the result of long-term effects of natural and human factors. The Tatra fauna was particularly influenced by the cold periods (in the ice ages), from which the descendants of species inhabiting the northern taiga and tundra came [50]. The cold seasons were followed by warmer seasons with thermophilic species from eastern and south-eastern Europe. The Tatra fauna is therefore characterised by various geographical components, including mainly cosmopolitan, Palearctic, European (Euro-Siberian, Boreoalpine, Boreal, Samaric, Sudeten Carpathian) and endemic species.

A colourful metallic coloured *Carabus auronitens*, *Carabus fabricii* get into the subalpine and alpine zones. From the butterflies there are, for example, species of the genus *Erebia - Erebia pandrose* and *Erebia manta*, a glacial relic *Parnassius apollo*. Few species of amphibians get into the alpine zone, e.g. *Rana temporaria*, *Triturus alpestris* [50]. Only two reptile species, and even these only rarely, get into the alpine zone, namely *Lacerta vivipara* and *Vipera berus*. Regarding birds, alpine meadows and rocky habitats are inhabited by *Prunella collaris* and *Anthus spinoletta*, as well as *Phoenicurus ochruros*, *Oenanthe oenanthe* and*Lyrurus tetrix*. A frequent visitor to these locations is *Aquila chrysaetos*, *Falco tinnunculus* and *Corvus corax*.

The mammals in the subalpine and alpine zones, include relict species of the*Pitymys tatricus*, t*Microtus nivalis mirhanreini*, *Marmota marmota latirostris* and *Rupicapra rupicapra tatrica*, which are existentially bound only to these habitats. Sporadically, *Ursus arctos*, *Canis lupus*, *Lynx lynx*, *Vulpes vulpes* [50] get into the habitats of the alpine zone. Insectivores are represented by the species *Talpa europaea*, *Sorex araneus*, *Sorex minutus* and *Sorex alpinus*.

3. History of human activities in the territory and their consequences

The Tatras were surrounded by one large primary forest until the 11th century. Until the 14th century, only isolated shepherds, treasure hunters and lumberjacks [13] had strayed into the valleys. Later, the territory was influenced by pastoralism, mining, hunting and poaching, hiking, mountaineering and tourism. Thus, the scale and structure of the original landscape of the mountain range have been disrupted by human activity for centuries.

3.1 Pastoralism

Major changes occurred in the 14th–17th centuries, when Wallachian colonization was directed to higher mountain areas. The foothills of the Belianske Tatras were chronologically grazed as the first of the entire Tatras. Pastoralism used almost all vegetation cover, the average height of the upper limit of pastures reached up to 2000 m MSL and grazing took place even on very poorly accessible terrain [13]. Wooden huts of mountain sheep farming in the Belianske Tatras lay at an average height of almost 1500 m MSL. In the years 1891–1895 there was also a cheese factory north of the Belianska kopa. According to statistical data, the grazing culminated in the Belianske Tatras in 1803 [51]. At the time of the enactment of TANAP, landowners in the Belianske Tatras continued to have herds. The year 1955 was the last year of grazing in the Belianske Tatras [52].

The considerable consumption of wood at the salaše, but also the deliberate destruction of stands with the intention of expanding the grazing area contributed substantially to the disruption of the climatic upper limit of the forest (up to 200–300 m) and in many places the zone of shrubland almost completely disappeared. Meadow and pasture communities have become replacement communities after felled forests or burnt shrublands. The originally vast shrublands have been removed. On the secondary mountain grasslands (**Figure 9**) we may find *Calamagrostis villosa*, *Avenella flexuosa*, *Crepis conyzifolia*, *Trommsdorffia uniflora*, *Pulsatilla scherfelii*, *Homogyne alpina*, *Anemone narcissiflora* and others. However, fellings outside the peak subalpine zone paradoxically also contributed to greater landscape and biological diversity by creating pastures, larger meadows and polonyas in the forests [53].

The burning of shrublands in order to spread grazing seriously disturbed the original ecosystem, which led to erosion of the soil cover and violation of the water regime with all associated negative consequences (e.g. deterioration of the absorption ratios [53].

After the end of grazing, there was a change in the herbaceous vegetation. Favourable results were apparent within two years of the end of grazing [54].

Figure 9.
A territory grazed in the past (Piscová, 2013).

The number of synanthrope species decreased significantly, grass representation decreased and the number of vascular plants increased, secondary plant communities thus gradually disappeared, shrubland became naturally younger and succession progressed. However, on former pastures there are abandoned soils that are not able to produce and are difficult to regenerate, and there are, for example, old roads to sheepfolds left by shepherds, which are only slowly being overgrown. Negatives associated with the succession and overgrowth of former flowery mountainous grasslands with monotonous overgrowth of competitively very strong species of the genus *Calamagrostis*, oat (*Avenula* sp.) or the species of thistle (*Deschampsia cespitosa*), which usually cause irreversible changes in the composition of the original phytocenoses [55], have also been shown. However, negative effects that persist to this day include the inability to restore vegetation on soils damaged by wind and rain erosion, the formation of snow and stone avalanches [13].

3.2 Mining

During the Turkish invasion of Central Europe in the 16th century, mining also began to develop here. The development of mining led to the appearance of coal miners who burned wood into charcoal for furnaces in which ore was melted. Copper ore was mined in Kopské sedlo, silver was mined in Belianská kopa and gold in Jatky. The mining sites were still visible at the end of the 19th century. Gold was sought on Belianska kopa and on the ridge between Kopské sedlo and the Jahňací štít. Mines on Belianska kopa are documented by the charter of the town of Spišská Belá from 1585 [52]. Despite the enactment of the Tatra National Park in 1949, mining activity in the territory was definitively prohibited only by the Act of the Slovak National Council No. 287/199 Coll. SNR on State Nature Conservation [56].

The most obvious traces of mining were destroyed stands with consequences in the form of bad drainage conditions and losses of forest land. Therefore, a very significant element was that it changed the character of the region mainly due to the emergence of bare slopes. Nevertheless, since then, deliberately by foresters, but also by natural processes, these changes have softened or even disappeared [13].

3.3 Aromatic plant-based oil industry

In the alpine landscape, oilmen sought sustenance by the acquisition of medicinal oils and herbs and in their trade with them. In addition to balm, conifer oil and medicinal herbal extracts were used to produce other essences that were used in the treatment of the sick and in religious ceremonies [57]. An important location for oilmen in the Belianske Tatras was the Predné Meďodoly, where the so-called terpene and shrub oil factory was established [58]. It was located near the Biele plesá tarns. In 1890, the idea arose to develop a large-scale production of shrub oils. In 1897, the city of Kežmarok concluded a contract with the right to extract any quantity of shrub in the valleys of the Biela voda, the Zelené pleso tarn and the Biele plesá tarns and to distill aromatic oils from them on the spot. A working-class dormitory and a factory of medicinal 'oleum Pini pumilionis' shrub oils were built near the Biele plesá tarns. Due to a violation of the forest law of 1879, the contract was cancelled and the buildings were demolished. Pinus cembra oil "balsamus carpathicus" from the pinus cembra needles, twigs and cones [59] also played an important role in Spiš medicine.

The oil industry had a degrading effect mainly on shrub and pinus cembra stands.

3.4 Hunting and poaching

In the past, the owners of the Tatra mountainous territory, the kings and later the lower nobility, ordered their subjects to hunt in the area with the establishment of a mandatory game amount. The German prince, Prince Christian Kraft Hohenlohe, who bought a part of the Belianske Tatras in 1879, was one of the greatest hunters in the Tatras. He set up a game reserve here, in which people hunted until 1922 [60]. There were also poaching events in the Belianske Tatras, especially aimed at the marmot and chamois [57]. Poaching increased the most during the years 1919–1922. Due to extinction of the marmot in the Belianske Tatras, the restitution of marmots took place in 2009.

Hunting and poaching significantly affected the autochtonous fauna, which persisted even after the icing of past periods [61].

3.5 World Wars

The period of World War I is associated with a decrease in the number of grazed sheep in the Belianske Tatras, the number halved compared to 1803 [59]. During World War II, the German army captured the territory of the Belianske Tatras. Under the Hlúpy vrch, soldiers established a high-mountain firing position. In the massif of the Hlúpy vrch, or between the Hlúpy vrch (2060 m MSL) and the Zadné Jatky (2019 m MSL) there are preserved bunkers of the German army and trenches for artillery fire positions carved in the rock. The transport of military equipment, ammunition, food and necessary material to the ridge of the Belianske Tatras was provided from Tatranská Javorina through the Zadné Meďodoly by Soviet prisoners guarded by German soldiers [62]. Bunkers – artificial underground spaces were built in a mining way with the help of explosives documented in 1993–1995 by speleologists [63]. The limestones of which the bunker is formed are heavily cracked due to the method of construction (blasting). The Germans' stay on the ridge of the Belianske Tatras was reflected in the condition of the chamois. [51] states that the soldiers contributed to the strong decimation of the marmot population as well.

3.6 Tourism

In the past, coal miners, treasure hunters, hunters, but also domestic nobility, stepped into the valleys and on the peaks. In the dense Tatra forests, robbers and deserters, smugglers or serfs found their refuge. Only in the 16th century can we consider the discovery of the Tatras associated with the first attempts at tourist walks [61]. The first tourist hike in the study area was made by Kežmarok castle's lady Beata Laská in 1565 [59]. The mountains began to be visited by educators, students, and later especially by the public.

The construction of hiking trails in the study area dates from 1879. In 1898 the Veľké Biele Pleso tarn received a tourist connection from Tatranská Kotlina. The extension of this trail to Kopské sedlo was established in 1905. The hiking trail continues from Kopské sedlo through Zadné Medďodoly to Tatranská Javorina. In 1938, a new trail to Predné Meďodoly was built, because the original path was exposed to falling stones, landslides and snow avalanches [59, 64].

In 1922, the army, together with the Czechoslovak Tourist Club, built a cottage with two rooms near the Veľké Biele pleso tarn, which later became overnight accommodation for tourists. However, the Kežmarok hut burned down in 1974. The design of the new Kežmarok hut from 1985 was in the end rejected [65].

The Belianske Tatras in the past had the attribute of extremely popular mountains for tourists, they were easily accessible, undemanding and with a ridge without extreme height differences. Due to the natural environment and the view of the countryside, they were very actively used. The maximum traffic was also several thousand visitors per year [66]. The attack on this very sensitive territory in the form of an excessive number of tourists manifested itself quite strongly. Disturbed chamois migrated from the ridge to the forest, where they were threatened by beasts; golden eagles left their nests, the number of bears decreased, and the almost complete destruction of some botanical species such as *Leontopodium alpinum*, *Gentiana clusii* and *Aster alpinus* was also alarming [67, 68]. With an enormous number of tourists on the ridge, there were secondary negative phenomena, such as shortening of trails, trampling around them and pollution of the natural environment with garbage and excessive noise [67]. The TANAP Administration therefore announced on 1 July 1978 the complete and long-term closure of the area to the public with a view to restoring ecological equilibrium. Until 1983, even scientists could not enter the Belianske Tatras [69]. Pressure from the public and various interest groups to make the Belianske Tatras accessible are constantly increasing. A compromise between the interests of tourists and the State Nature Conservation of the Slovak Republic was the opening of the educational trail in the Monková dolina valley in 1993 (one-way, payment for entry). Since 2008, this educational trail has been open both ways free of charge. In the Tatras, the seasonal closure of trails along the Tatra huts from 1st November to 15th June applies to ordinary tourists.

4. Land-cover change in the area, with a particular focus on vegetation

In the Tatras, natural destructive factors have operated, operate and will always operate, but nature has dealt with them in the course of evolution and they do not pose a critical threat. It can eliminate their consequences very quickly. Man, and his activities have become the biggest negative factor in the course of history. Nature can cope with anthropogenic interventions with much more difficulties and must spend more energy maintaining the equilibrium or regenerating damaged components.

Land cover until the enactment of the national park was most intensively shaped in the studied area by shepherding and later by aromatic plant-based oil industry. Belianske Tatras were liberated from grazing and devastation by the SNC Act No. 11/1948 Coll. on the Tatra National Park [28], when, with effect from 1 January 1949, Belianske and High Tatras were declared our first national park – the Tatra National Park (By order of the SSR Government No. 12/1987 Coll. of 6 February 1987 [70], Western Tatras were also declared a part of TANAP). However, grazing was definitively abolished throughout TANAP only in 1954 [53].

Several studies from the territory claim [71, 72] that the change in land use since the enactment of the national park led to the spontaneous afforestation of land abandoned after the restriction of grazing (in order to protect nature), at the same time tourism was actively developing and local people were changing their orientation from agriculture to tourism.

The studied area falls under three cadastral territories: Tatranská Javorina, Tatranská Lomnica and Ždiar. In the cadastral areas, the spatial structure of the land cover for the period 1955–2010 [73] was analyzed. In all areas, there was a decline in the loss of coniferous forest, along with an increase in damaged forests, especially on the southern slopes in 1955–1986 and 1986–2010. In the area of Tatranská Javorina, a significant change was found in the proportions of alpine meadows and shrubland (*Pinus mugo*), especially on slopes facing south and south-west, by increasing the vegetation of the shrubland in places with higher altitudes, lower degree of slope and less sunlight, and in places with lower altitudes where radiation and the degree of slope are higher. In the area of Ždiar, an increased proportion of shrublands was observed in higher places, on moderate south-western and western slopes. In the period 1955–1968, there was an increase in shrubland (*P. mugo*) and a decrease in alpine meadows in locations with higher altitude and lower degree of slope. In the period 1968–2010, the increase of shrubland in relation to losses in coniferous forests prevailed. As in the area of Javorina, the study attributes the increments of shrubland to higher radiation and slopes at lower altitudes. Also, in the area of Tatranská Lomnica there was an increase in shrubland (*P. mugo*) for the period 1955–1968. There was more shrubland in places with higher altitudes and milder slopes (mainly in the south-west, west, north-west and north); in the period 1968–2010, increments of shrubland (*P. mugo*) were recorded more or less independently of other variables. In general, the increments of shrubland correspond to the declines of alpine meadows, the cover ofshrubland increased at higher altitudes: (1) mostly in sunny and less steep places and slopes and (2) at lower altitudes on sunny and steeper slopes. Decrease of shrubland in lower positions may be evidence of the spread of coniferous forests into higher altitudes, but none of the selected abiotic variables explain this change.

The results of the analysis show a slight upward shift of vegetation from 1956 to 2012. The most pronounced shift concerned shrubland (*P. mugo*). The spread of shrubland confirms the findings of several studies [71, 74, 75], which claim that the visible expansion of shrubland to higher altitudes is due to the abandonment of traditional land use, but also to better temperature conditions (longer seasonal growth, milder winters and shorter periods of snow cover) with sufficient water. On the other hand, the historical influence of man on vegetation in the Tatras is significantly limited by attempts to identify changes that are caused exclusively by climate change. According to some historical sources [76], the boundary of forest trees was lowered (especially in the Belianske Tatras), by 200 m on average, and by 350–400 m or more in some places. The declaration of the National Park (1949) and the subsequent ban on grazing (1954) were the main driving forces behind these changes in the Tatras.

5. Changes in the floristic composition of the peak vegetation in the territory since 1880

Plants are also sensitive to an increase in anthropogenic effects on the Earth's climate system [77]. Between 1957 and 1966, the number of species on mountain peaks in Europe increased by an average of 1.1. Since then, this trend has accelerated, so since 2006 and 2007, an average of 5.5 new species have moved to the highest mountain peak locations in a decade [78].

The same trend was observed in our study area, where, despite the general decline in species richness with increasing altitude, there was a clear percentage increase in the number of species between time periods (**Figure 10a, b**).

Ellenberg indicator values for the central-European flora [79] are routinely used to rapidly estimate site conditions from species composition, when measured

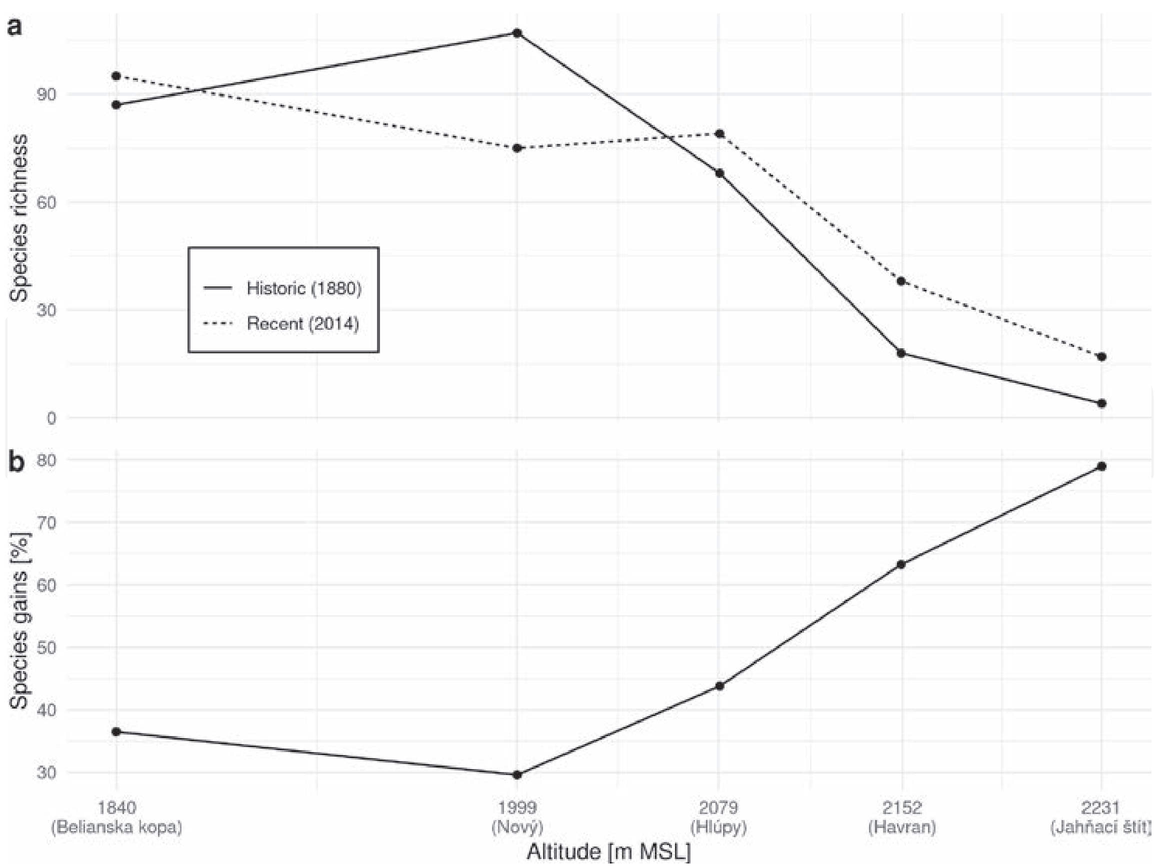

Figure 10.
a. Species richness in relation to altitude at different times; 10b. Percentages of species gain between the studied time periods (1880, 2014) in relation to altitude. Gain was calculated as: g/Stot where g is the number of species gained and Stot is the total number of unique species in both time periods.

values of environmental variables are not available [80, 81]. These indicators are estimates of species ecological optima along several main ecological gradients. Subsequent analyzes of Ellenberg's environmental indicators, using linear mixed modes (to pair design), showed significant differences between time periods in the light ($F1{,}390 = 5.14$; $p = 0.024$), and soil reaction ($F1{,}392 = 6.17$; $p = 0.013$) indicator. Despite its statistical significance, the simple effect sizes (lightmean_diff = −0.28; soil reactionmean_diff = −0.65) were not significant enough to lead to more convincing conclusions.

6. Current land use and its bearing capacity for given activities

The current use of the studied area depends on the status of the national park. It can monitor and examine the dynamics of ecosystem development, its accessible part serves for the needs of education, interpretation, communication, tourism, recreation and the necessary infrastructure for the administration and guarding activities of the National Park Directorate.

However, the attractiveness of the Tatras, the smallest mountains in the world, is manifested by high tourist attendance in the long term. In the territory of TANAP there are about 600 km of marked trails that will lead tourists to the most interesting places. Hiking trails through the valleys allow ascents to the Tatra huts, some demanding and less demanding Tatra peaks, as well as passages through the Tatra saddles. The alpine landscape is thus under pressure from tourism and tourism-related activities.

6.1 Territory traffic

According to European Statistical Office [82], people living in Slovakia visit mountains the most of all European countries. Hiking is deeply rooted in Slovakia, with tourist traffic increasing every year. This trend is also confirmed by the data on the annual number of overnight stays in the High Tatras (**Figure 11a**).

We can see a similar short-term trend on one of the studied tourist routes Šalviový prameň (1213 m MSL) to Veľké Biele pleso (1615 m MSL) (**Figure 11b**), where we can see a steep increase, especially during the COVID pandemic restrictions (which also explains the rapid decline in the number of overnight stays in **Figure 11a** in 2020).

We believe that this increasing trend will continue, which may further affect the plant community composition and structure, even more.

6.2 Hiking and its impacts

A number of human activities in the alpine landscape began and ended over the years. However, one of them lasts almost 150 years and remains the only one to this day-hiking. The vulnerable territory of the studied area is affected not only by the bearable or unbearable number of tourists on the trails, but also by its location and the surface itself, which may constitute barriers for tourists**.**

6.2.1 Trampling impacts on vegetation

Another serious fact is trampling of the vegetation cover. Trampling is known to drive changes in plant community composition and structure [84–87]. Disturbance by trampling mainly affects vegetation directly by damaging plant tissues [88], and

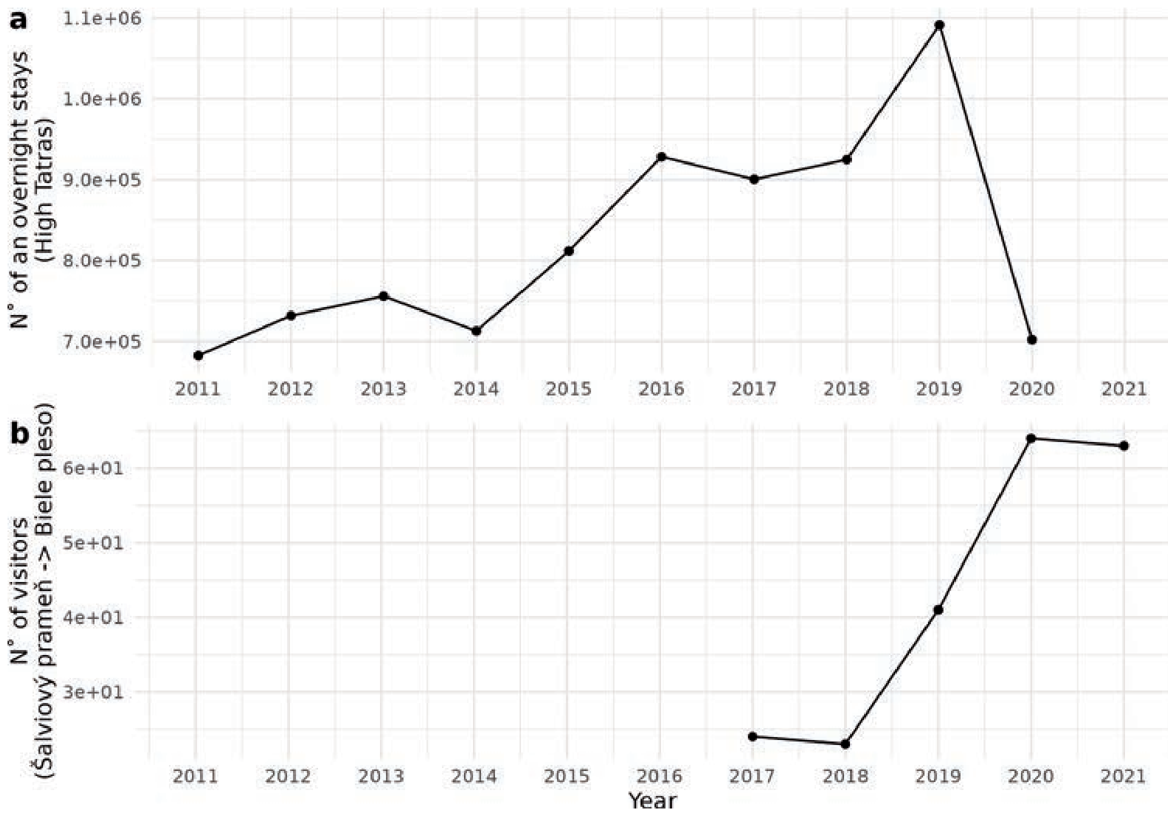

Figure 11.
a. Number of overnight stays in High Tatras area [83]; 11b. Number of visitors on the trail from Šalviový prameň (1213 m MSL) to Veľké Biele pleso (1615 m MSL), source: Správa TANAPu Tatranská Lomnica.

indirectly by modifications to soil structure [89], water regime [90], and nitrogen mineralization [91]. Other evidence indicates that the effects of trampling on soil compaction remain unclear [92–94], or at least are important only in areas of chronic disturbance (long-term effect) [95]. For single disturbance events, the direct effects of the damage to plant tissues are generally the most important [89]. Plants with similar ecological traits are estimated to respond to trampling in comparable ways [96]. Therefore, we have tried to find how the selected vegetation types resist trampling in three alpine communities: *Juncetum trifidi*, *Junco trifidi-Callunetum vulgaris* and *Seslerietum tatrae* using a standard short-term vegetation tracing protocol from Cole and Bayfiel [84]. However, we adjusted the design of trampled blocks and also changed the number of trampled areas according to the number of visitors to the site.

We based the evaluation of the resistance of species monitored on permanent surfaces on relative coverability. We based the calculation of the relative coverability on the sum of coverages of all types, which we preferred over a simple estimate of the total coverability [84]. **Figure 12** shows that there was a statistically significant interaction between trampling intensities and localities on the sum of the coverages ($F1.35, 12.12 = 45.6$, $p < 0.0001$). Therefore, the effect of the trampling intensities was analysed at each locality. P-values were adjusted using the Bonferroni multiple testing correction method. The effect of treatment was significant at all three localities (for Ks = $F1.09, 9.79 = 48.5$, $p < 0.0001$; PKs = $F1.01, 9.06 = 70.3$, $p < 0.0001$; VKs = $F1.1, 9.9 = 44.2$, $p < 0.0001$).

Our study [97] confirms earlier conclusions which stated that more resistant woody chamaephytes have less recovery abilities because of their woody habit. The statement that some communities are initially very prone to trampling due to the

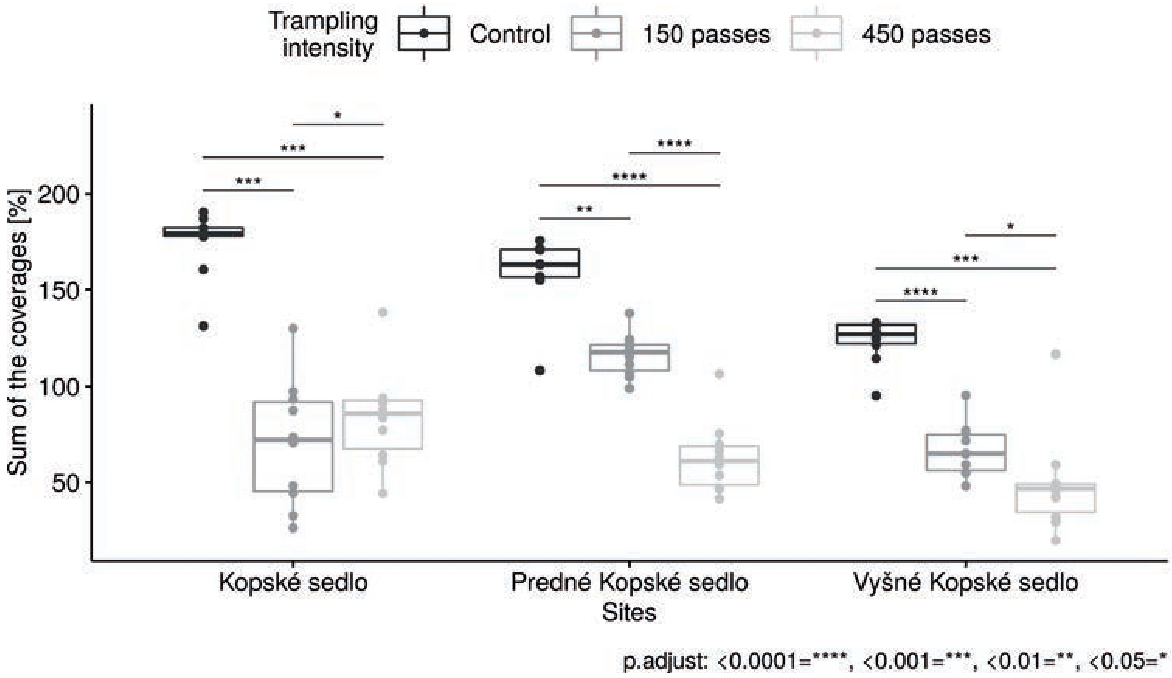

Figure 12.
Differences of sum coverages of all species between different trampling intensities for every locality [80].

high amount of sensitive herbal species was also confirmed. These plant associations are characterized by low, middle and high resistance to trampling, but hiking trails passing through communities can still be made available to tourists at a given traffic.

6.2.2 Synanthropisation

Synanthropisation is manifested by ecesia of the habitat-foreign plants [98]. The most common way of spreading such plants is the transport of diasporas from lower-lying habitats to higher altitudes along the routes of hiking trails. The ecological plasticity of these plants is a limiting factor for their maximum altitude of occurrence. Another way of spreading for habitat-foreign plants is their transport from high mountain higher altitudes to lower altitudes. This applies to species native to the Tatras (original). They stick to ecotopes at a more advanced stage of destruction as a result of hiking. They are plants of apophytic or facultative synanthropic species. Facultative synanthropic species also include species spreading by succession from the forest environment to places deprived of vegetation (grassy) cover by trampling. In terms of the impact of synanthropization on changes in species richness depending on the distance from hiking trails, we found significant differences. The results of the analysis of variance showed a gradual increase in species richness with increasing distance from the trails (**Figure 13a**; $F_{2,9} = 11.96$; $p = 0.003$) by an average of 23% between distance categories. We also found differences in species richness between rest areas and their environs (**Figure 13b**; $t_4 = -5.15$; $p = 0.007$) by 34%. There are 5 synanthropic species in the area (*Plantago major*, *Plantago media*, *Prunella vulgaris*, *Taraxacum* sect. *Ruderalia*, *Tussilago farfara*) and 3 apophytic species (*Aegopodium podagraria*, *Chaerophyllum hirsutum*, *Urtica dioica*), which occur at a distance of up to 50 cm from the trails, while at the distance of up to 20 cm from the trail they reach the highest coverage of up to 5% and for 20–50 cm up to 2%.

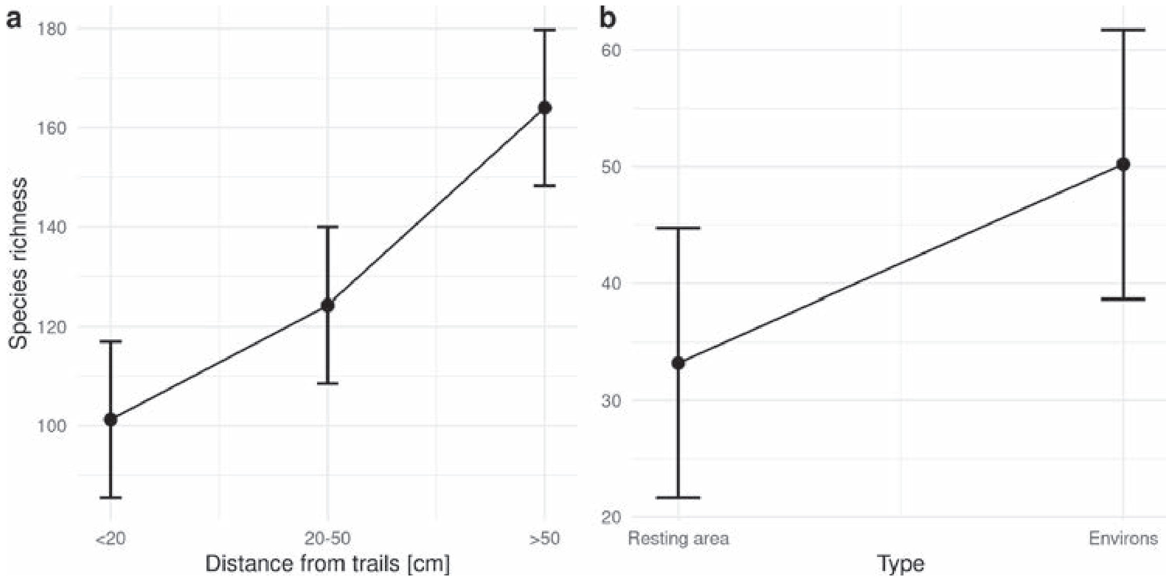

Figure 13.
a. Species richness differences in distances from hiking trails; 13b. Species richness differences in resting areas and their environs (whiskers represents 95% confidence intervals).

6.2.3 Branching, parallel trails and shortcuts of trails

When the surface of the trail is poorly treated, wind, precipitation and frost begin to affect the trail very intensively. As a result of intense erosive processes, the trail becomes

Figure 14.
Parallel trails in the Predné Kopské sedlo – the High Tatras (Piscová, 2011).

impassable for tourists and inappropriate also from the point of view of tourist safety, it constitutes an obstacle for tourists to be bypassed. This is how parallel replacement trails are created. In the studied area, the trails are accompanied by a number of parallel trails and shortcuts. The term parallel trail was originally used for a trail trodden by animals (e.g. chamois, cattle, etc.). Parallel trails were also created by trampling the vegetation cover when tourists walked off the trail. Parallel trails arise more often on small slopes, mainly in the grassland type of landscape, which allows tourists to deviate from the trail (**Figure 14** [55]). A trail with shortcuts is created mainly in places where the trail leads from saddles into valleys and has sharp turns – serpentines. New shortcuts as secondary trails have been created by undisciplined tourists close to the place of the largest curvature (bend) of the hiking trail to shorten their journey. The shortcuts are connected perpendicularly to the trails. They go in the direction of the greatest slope, thus conditioning the formation of erosion (**Figure 15**) [55].

6.2.4 Localisation of the hiking trail and morphodynamic processes threatening hiking trails

The location of a hiking trail should be in accordance with, or in the least contradiction with, the natural conditions of the territory. Otherwise, there is devastation not only of the trail itself, but also of its surroundings and the process of their regeneration is slow (**Figures 16** and **17**).

The subsoil in the studied area is susceptible to various forms of destruction by exogenous processes. Therefore, it is suitable only for a slightly concentrated, soft form of tourism.

Figure 15.
Shortcut on the hiking trail under the Vyšné Kopské sedlo – the Belianske Tatras (Piscová, 2011).

Figure 16.
Predné Meďodoly. Fading hiking trail, closed since 1978 (Piscová, 2010).

Figure 17.
Trail to Ždiarska vidla (2142 m MSL), closed since 1978 (Piscová, 2010).

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Routes of hiking trails on the south-western and south-eastern slopes of the Belianske Tatras are threatened by many processes [99] associated with avalanches, nivation, surface runoff, coming off of soil and weathered cover, debris flows, rock

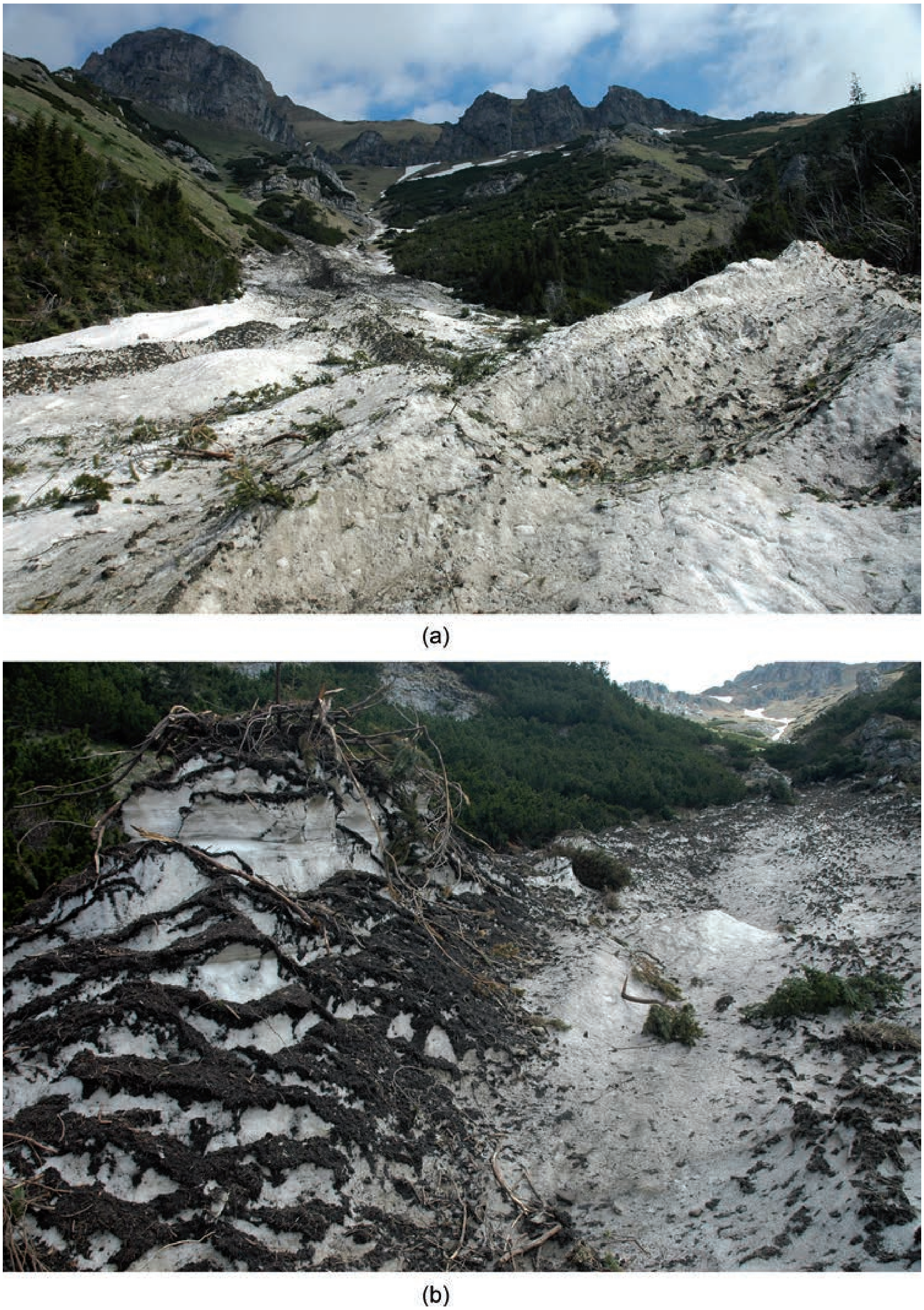

Figure 18.
Massive snow deposits covered the hiking trail after the avalanche event in April 2009 under the Ždiarska vidla (Hreško, 2009).

rushing and landslides (**Figure 18a, b**). Processes that arise in the immediate vicinity of the trails and are bound to their course – processes of nivation (dominant processes), erosive processes, gravitational descent of the weathered cover, slope-gravitational processes of the type of shallow landslides, eolithic processes in saddle and ridge positions.

Avalanches represent the process of movement of snow masses on mountain slopes, in avalanche troughs and in juvenile valleys. A special case of snow avalanches are "gliding avalanches", in which the soil-vegetation cover and the subsoil (including the trail) are destroyed almost in the entire width of the snow mass movement (**Figure 19**). An avalanche with a massive snow mass with a thickness of more than 2 meters and torn off fragments of rock substrate destroys vegetation and grinds the soil and weathered cover, which is documented by parallel grooves in the direction of the avalanche movement.

Another process endangering the trails associated with intense rainfall is debris flows. The limestone-dolomite subsoil of the exposed ridge of the Belianske Tatras provides a large amount of weathered, fragmentary material that forms the substantial mass of the flows. The most significant activation of debris streams occurred in 2016 (**Figure 20a, b**) at a precipitation intensity of more than 45 mm/h, which was confirmed by the analysis of the SHMI radar image.

The erosive effects of running water and concentrated surface runoff are mainly associated with torrential rains, which are involved in the fluviation of alpine ecosystems. Trails are in some places intersected by erosive grooves, which are formed in the gutters and on the bottoms of the juvenile valleys. Most often, the erosive effect is also manifested on the trails that represent local erosive bases (**Figure 21**) for the flowing surface water. This leads to significant destruction of trails and their deepening into more or less stable rock subsoil (**Figure 22**).

Figure 19.
The trail to Vyšné Kopské sedlo after a gliding avalanche (Hreško, 18 June 2009).

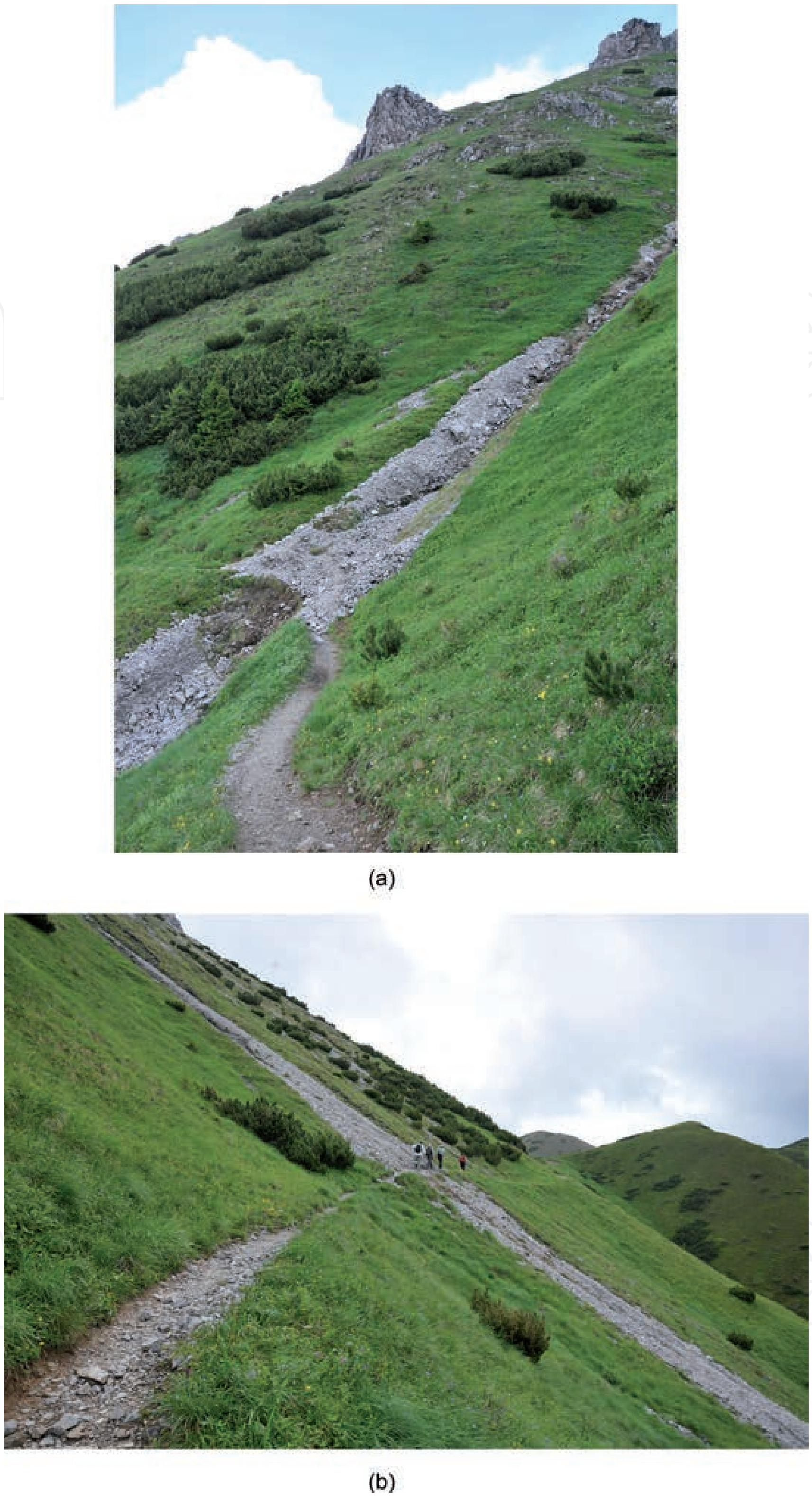

Figure 20.
Activated debris flows on the SW slope under the Hlúpy vrch after an intense downpour on 24 June 2016 (Hreško, 6 July 2009).

Nivation is a specific process, which is related to the long-term effect of snow fields on the hydric regime of the concave parts of slopes, especially if they are interrupted by a notch of a hiking trail. In the conditions of the SW slopes of the Belianske Tatras, we confirmed the occurrence of expansion cracks on the surface of the trails which were covered with remnants of snowfields for a longer time (**Figure 23a, b**).

Figure 21.
Fresh erosive groove near the trail under the avalanche trough of the Ždiarska vidla (Hreško, 6 July 2009).

The slow melting of the snow led to an increased retention of melt water, which reduced the stability of the soil-weathering layer and subsequently formed longitudinal expansion cracks. Such sections of trails have a high potential for slow coming off and descent. This is manifested by the sudden bends and dents of the trails, including their surroundings.

Nivation-eolic effects are concentrated mainly in the sub-ridge, ridge, sub-peak and saddle positions. The eolic-deflationary effect is based on the turbulent, backward effect of the flowing wind, which causes blowing off and removal of finer amounts of soil cover or even the nivation of the exposed weathered cover in the upper parts of leeward slopes, especially on the edges of the ridges (**Figures 24** and **25**). The

Figure 22.
Intensive deep erosion of the hiking trail under Kopské sedlo after an intense downpour in June 2016 (Hreško, 14 September 2016).

accumulation effect of both processes is destructive and does not allow a more successful process of vegetation succession. The eolic-nivation pads in the upper parts of the extremely steep slopes are often the source area of the initial debris flows, which, due to the smaller number of debris and fragments, may not reach the bottom of the slope, i.e. they remain "hanging" on the slope. The manifestations of wind erosion, more precisely the deflation of fine soil and weathering particles, focus mainly on the saddle and ridge positions of the Tatras. Another form conditioned by wind corrosion are eolic niches – pads with removed soil horizon of various shapes. Their edges are lined with overhangs, reinforced by root systems, which are intensively undermined by wind-blown particles. In cases of intense precipitation and snow melting, there is also a systematic washing out of niches and receding edges. Favourable conditions for the application of eolic deflation and corrosion are provided mainly by colourful shales

Figure 23.
Expansion cracks on the hiking trail after melting of the snow field on the SW slope of the Belianske Tatras (Hreško, 2009).

Figure 24.
Exemplary locations of the effect of eolic deflation of soil-weathered cover in the vicinity of Kopské sedlo (1750 m MSL) (Hreško, 2009).

Figure 25.
Vyšné Kopské sedlo, 1933 m MSL (Hreško, 2009).

and marls in the area of the Western and Belianske Tatras. The existing knowledge on the occurrence of eolic-deflationary forms is incomplete.

The slope gravity processes were activated in the form of shallow landslides of the soil-weathered cover as a result of intense rainfall or melting of snowfields (**Figure 26a, b**). In 2009, we found a landslide of the soil-weathered cover together with the vegetation cover of shrubland on the trail route in a shallow concave depression. The lithological properties of the geological subsoil were also applied to the formation of the landslide. In the area of interest, poorly reinforced, Mesozoic, hydrothermal altered limestone, lime, marly limestone, marl and shale are particularly susceptible to the formation of landslides.

6.2.5 Bearing capacity of trails in terms of their abiotic properties

The bearing capacity of the territory for the given traffic was addressed by several authors [100–104]. We have chosen the following parameter to evaluate the abiotic properties of trails and rest areas: gradient of the hiking trail, gradient of relief of terrain, rock resistance, soil types, surface coverage of hiking trails and the possibility of leaving the trail, according to the methodology [105].

According to our research [106], the trail leading from the Veľké Biele pleso tarn (1615 m MSL) to the Kopské sedlo (1750 m MSL) was characterized by medium bearing capacity in the lower sections and high bearing capacity in the higher parts. Therefore, in the vicinity of the trail we recommend to observe the erosion of the trail itself, the emergence of turf overhangs, in the event of trail impassability to strengthen its surface, we also recommend to intensify the patrol of nature guards in order to more closely monitor the frequency of attendance of the trail (rest area) and the movement of tourists outside the tourist-accessible places. The same applies to rest areas on the trail.

Figure 26.
Retrospective development of the slope along the tourist trail (1660 m MSL) below Hlúpy vrch (2061 m MSL) (Hreško, 11 October 2005, 2 July 2016).

In terms of abiotic properties of the trail and its surroundings, we can evaluate the bearing capacity of the trail from Tatranská Javorina (1000 m MSL) to Kopské sedlo (1750 m MSL) in the lower sections as high, in the higher sections as medium and in the final part before entering the Kopské sedlo as low. While in the lower parts we recommend to monitor the erosion of the trail itself, the emergence of turf overhangs, in the case of impassability of the trail to strengthen its surface, we also recommend to intensify the patrol of the nature guards due to a closer monitoring of the frequency of attendance of the trail (rest area) and the movement of tourists outside the tourists-accessible places. In the section before entering the saddle it would be necessary to reduce the frequency of attendance of the trail (rest area) by 50%, i.e., to leave the trail open only in one direction. Due to the entire length of the trail, it is possible to keep the current attendance.

The trail leading from the Široké sedlo (1825 m MSL) to the Kopské sedlo (1750 m MSL) is characteristic in terms of abiotic properties of the area through which it extends, medium and high bearing capacity (medium over high). Therefore, in the vicinity of the trail we recommend to observe the erosion of the trail itself, the emergence of turf overhangs, in the event of trail impassability to strengthen its surface, we also recommend to intensify the patrol of nature guards in order to more closely monitor the frequency of attendance of the trail (rest area) and the movement of tourists outside the tourist-accessible places.

7. Conclusions

The High Tatras mountains represent a unique alpine landscape with which humans have been connected since the past. The Belianske Tatras represent the limestone part of the mountain range. With rare communities and many endemics and glacial relicts, they are among the rarest and most endangered mountains of Slovakia. The High Tatras with glacial relief on crystalline basement and specific climatic conditions, represent the most attractive area of the Slovak high mountains. Tatras are the smallest mountains in the world. Like any other mountain range, the Tatras were first recognized by man, later he harvested wood, mineral richness, used grasslands as alpine pastures. Over time, however, one realized the uniqueness, rarity and value of the alpine landscape and began to protect it. At present, this area is protected as a national park, the Tatras Biosphere Reserve, the Habitats Directive and the Birds Directive. In the study area, all activities except recreation, sport, tourism, research, education and the construction of the necessary infrastructure are excluded.

With the enactment of the Tatra National Park in 1949, there were changes in the use of the territory of the Tatras. Since the Middle Ages, most villages in the Tatras had not been satisfied with the use of their mountain pastures and began to practise seasonal grazing on Tatra grasslands. After the end of this most intensive activity in the studied area, there has been a secondary succession towards greater stability. However, this process is not yet complete. In general, it can be stated from the results of the research that the former pastures gradually overgrow with forest cover and that the shrubland enters higher parts. The regeneration process is slow, as the recovery of this species in mountainous conditions is more difficult. Since the enactment of the national park (1949), the study area has gradually regenerated, but until now it has been mainly dealing with the surface grubbing-up of shrubland and grazing.

However, adverse changes in the studied area occurred even after the national park was enacted. They consist of visual disturbances, symptoms, as negative signs in the form of erosive manifestations that arose as a result of mass tourism on the ridge parts of the Belianske Tatras. The protection of the territory ensured the exclusion of those activities. Although there has been no development of tourism and infrastructure construction in the area, the Belianske Tatras ridge trail has been closed since 1978, one of the trails leading through the Monkova Valley has been open since 1993 in one way, and since 2008 again in two ways. The closed ridge trail regenerates here very slowly despite the long period of time. Most of the trails in the Belianske Tatras were inappropriately founded. In addition, the practice of guarding nature reveals numerous non-compliance with the entry ban. The most devastated parts of the trails here include places on long straight horizontal to diagonal traverses approximately in the middle parts of steep grass-herbal slopes, where disruption of the vegetation and soil-weathering layer created a local erosion base for water-gravity processes. All hiking trails in the area are endangered by many morphodynamic processes and the devastated parts of the trails form obstacles for tourists.

Tourist attendance has a number of direct and indirect impacts on the natural environment [107], so its monitoring is important. The situation in Slovakia is relatively non-specific in this case compared to other countries, as the systematic collection of tattendance data is missing. In most cases, the application of direct methods within Slovakia was associated only with the implementation of specific short-term projects [108] and so far there is no year-round continuous automatic monitoring of attendance, which cannot fully replace even several-day annual manual counting of visitors in the summer season in some areas of the Tatra Mountains [55].

From the point of view of sustainable development, it would make sense for the tourist closure of the ridge trail of the Belianske Tatras to continue with an appeal for preservation for future generations. Since uncontrolled tourism in a forbidden environment is more dangerous than a limited variant of ecotourism, the authors of the study [57] have reached the possibility of managing soft tourism in the territory, with supervision in the form of a guide. We recommend to monitor attendance and damaged habitats in the territory. A significant shortfall in mass tourism still remains minimal work with visitors to raise their environmental awareness as a means of reducing negative impacts on nature. What contributes to this is the lack of experience of municipalities, owners and administrators of protected areas in the regulation of tourism, as well as the lack of cooperation between the administrators of protected areas and tourism representatives.

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Author details

Veronika Piscová[1*], Juraj Hreško[2], Michal Ševčík[2] and Terézia Slobodová[2]

1 Institute of Landscape Ecology of Slovak Academy of Sciences, Nitra, Slovakia

2 Department of Ecology and Environmental Sciences, Constantine the Philosopher University in Nitra, Nitra, Slovakia

*Address all correspondence to: veronika.piscova@savba.sk

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