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TIMBERLINE IN THE CARPATHIANS: AN OVERVIEW

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Abstract

In nature, division lines are delineated where multiple important environmental features change. These division lines may be singled out at the intersection of two geosystems (Balon 2000) where the functional uniformity of the geosystems located on both sides are preserved (Forman & Gordon 1986; Cadenasso et al. 2003). A significant environmental boundary is the upper forest boundary (*timberline*), which separates different vegetation zones: (1) forest from non-forest (Piękoś-Mirkowa & Mirek 1996); climatic zones (2) cool from very cool (Hess 1965); geoecological zones (3) periglacial from temperate forest system (Kotarba 1996). A timberline is a sensitive ecosystem therefore is a good indicator of changes occurring in the environment. There are, however, multiple elements which affect the timberline. This ecotone has also been widely analysed in local, regional, and even monographic studies of numerous massifs. It is necessary to present and organise the great amount of information in order to aid research on the timberline in the Carpathians.

Key words

boundaries in the mountain environment • timberline • Carpathians

The notion of boundaries in the geographical environment

The question of boundaries appears in every study involving a spatial dimension of research (German 2000). Based on their origin, three types of boundaries can be distinguished: natural, anthropogenic, and agreed (Armand 1980). In nature, the division lines may be singled out at the intersection of two geosystems, where multiple important environmental features change (Balon 2000). The functional uniformity of the geosystems located on both sides is then preserved (Forman & Gordon 1986;

Cadenasso et al. 2003). Both biotic and abiotic as well as natural and anthropogenic factors affect the shape of the boundary. Natural boundaries are not usually sharp and have a transitional zone, called an ecotone. Elements from both areas occur in an ecotone, organisms from adjacent biocoenoses coexist, which leads to an increase in biodiversity (Allen & Starr 1982; di Castri et al. 1988; Hansen & di Castri 1992). The bigger the difference between the adjacent environments, the narrower the ecotone zone. The features of an ecotone are determined by time, development, and function: permeability, durability, and flexibility (Hansen & di Castri 1992). Plants and animals achieving their environmental limit are exposed to tension and environmental stress. For that reason, an ecotone constitutes a good bioindicator of various changes occurring within the ecotone's range (Gosz & Sharpe 1989).

A timberline is a good indicator of changes occurring in the environment. There are, however, multiple elements which affect a timberline. This ecotone has also been widely analysed in local, regional, and even monographic studies of numerous massifs. It was necessary to present and organise below, the great amount of available information for the purpose of researching the timberline in the Carpathians.

The notion of timberline

Several boundaries can be distinguished in a high mountain environment (Troll 1972, 1988; Price 1981). Usually there is a division into layers, when climate and other environmental components change together with the above sea level altitude. Outermost boundaries have different origins. The abiotic boundary of eternal snow, above which mountain glaciers may appear, is located the highest (Paterson 1994). Whereas in dry climates, the drought-caused timberline (*lower timberline, dry timberline*) is located in the mountain foothills. In the Carpathians, where the climate is humid, this boundary does not occur, but centuries of human activity resulted in the formation of an agricultural and forest anthropogenic boundary (Adamczyk et al. 1980; Sarmiento 2002; Kozak 2005).

A significant environmental boundary is the upper forest boundary (*timberline*), which separates different vegetation zones. These zones are: (1) forest from non-forest (Piękoś-Mirkowa & Mirek 1996); climatic zones (2) cool from very cool (Hess 1965); geoecological zones (3) periglacial from temperate forest system (Kotarba & Starkel 1972; Kotarba 1996). The adjective 'alpine' was added to the boundaries occurring in high-mountain systems and this word is also used nowadays (Brockmann-Jerosch 1919).

Scientific research articles provide multiple definitions of the upper forest boundary. These definitions have been modified with time. The differentiation between an ideal and empirical definition of the forest boundary was made as early as the beginning of 20th century (Fries 1913). However, even nowadays, numerous discussions are held on the definitions and their terminological differences. Although the available information on this subject has grown considerably since the 1990s, the Timoney's remark has maintained its accuracy: "(...) the tree line and other subarctic-arctic boundaries have been defined more often than they have been mapped" (Timoney et al. 1992).

The most common definition is the one of a potential/ hypothetical/ generalised upper forest boundary ('treeline') (TL) (Imhof 1900; Marek 1910; Fries 1913; Sokołowski 1928; Plesník 1971; Troll 1972). This would be the line connecting the uppermost patches of dense forest, which corresponds to the course of climatic upper forest boundary (Fig. 1). Heat deficiency is the global factor which determines the treeline existence (Daubenmire 1954; Hess 1965; Walter & Medina 1969; Holtmeier 1974).

In reality, a potential treeline is affected by various elements, and therefore, a lot of research is focused on the actual course of a timberline (TE), called by Fries (1913) an empirical timberline (eTE). The term was changed into an empirical upper timberline

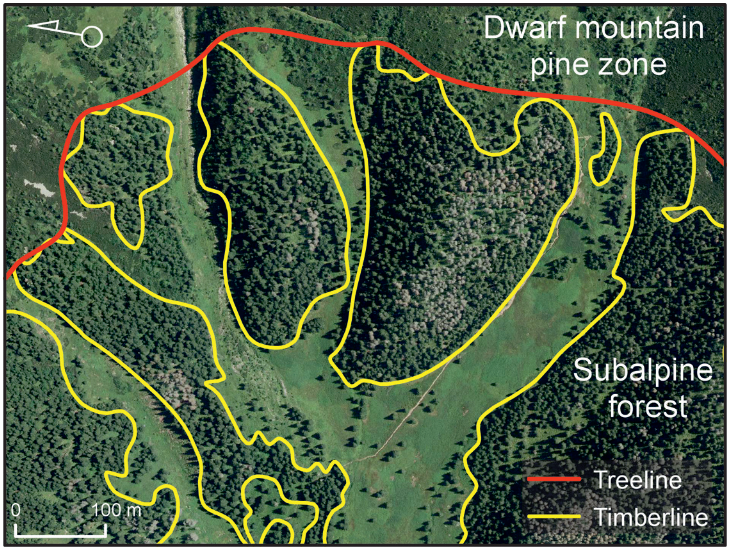

Figure 1. Spatial differences between treeline and timberline delineation

by Sokołowski (1928) for the purpose of the research carried out in the Tatras. An empirical timberline refers to the line connecting the highest locations of a dense forest and this line reflects the impact of all natural and artificial factors (Fig. 1). It is also called a biological timberline (Hustich 1953). Definitions of a *timberline* in English correspond to a dense forest boundary, but there are multiple variations of this term.

The large number of these terms, their interchangeability and misinterpretation result from various methodological criteria but also their application to the tree species range zones at different latitudes and in different climates (Troll 1973a,b). Moreover, the scale of the analysed areas is quite varied. On the one hand, there are studies on very small mountain areas like the Babia Góra Massif (Czajka et al. 2015a) or single valleys (Jodłowski 2007), which call for applying methodologies which emphasise the details and nuances of the investigated subject (1:10,000 or 1:5,000 scale mapping). On the other hand, when similar issues are examined for the extended mountain ranges, e.g. entire Alps (Brockmann-Jerosch 1919) or Carpathians (Weisberg et al. 2013) the results must be presented in the form of synthetic characteristics.

Numerous studies have been devoted to differentiating between a dense forest and a non-forest area. Such a differentiation is necessary to map out a linear spatial division between the dense forest and non-forest area. This division would be the empirical timberline. Three main criteria must be taken into account: the height of the trees, the crown cover/canopy cover/forest density, and the forested area. The fourth criterion is a secondary one – tree species (Tab. 1). According to many authors, trees growing on the forest side of the eTE should reach a height of 4-5 m (Schröter 1926), and up to 8 m (Sokołowski 1928; Vincent 1933; Zientarski 1985) or even 12 m for a beech timberline (Kucharzyk 2006). Minimum crown cover (that is how and to what extent tree crowns fill in the space of a tree stand, after Szymański 2000) was determined as: low (≥0.4) (Fekete & Blattny 1913-1914) or medium (>0.5) (Plesník 1971), while in the case of beech forests – very dense (Kucharzyk 2006). According to Aas (1964) and Mork (1968), a forest can be called dense when the average distance between trees does not

Table 1. The criteria used for determining an empirical timberline in Europe according to different authors

Author	Location	Species	Altitude [m a.s.l.]	Minimal height of trees [m]	Extent of forest density	Area [m^2]	Others
Fekete & Blattny (1913-1914)	Mountains of the former Austro – Hungarian Empire	Spruce	~2000	8	low density ~0.4	Not specified	Distinguished between the 'timberline' and the 'treeline'. Not specifying whether they meant empirical boundaries
Brockmann-Jerosch (1919)	Central Swiss Alps	Spruce, Larch, Swiss pine	2250	5	Not specified	Not specified	Introduced the term *alpine* timberline
Däniker (1923)	Alps	Spruce, Larch, Swiss pine	~2200	*	Not specified	Not specified	
Schröter (1926)	Alps	Spruce, Larch, Swiss pine	~2200	4-5	Not specified	Not specified	Elaborated on the definition of struggle belt (*kampfzone*)
Sokołowski (1928)	Tatra Mts.	Spruce, Larch, Swiss pine	~1700	8	low density	Not specified	
Vincent (1933, 1938) after Guzik (2008)	Vysoké Tatry Mts.	Spruce, Larch, Swiss pine	~1700	8	Forest cover >0.5	>10,000	
Svoboda (1934) after Guzik (2008)	Tatra Mts.	Spruce, Larch, Swiss pine	~1700	8	Not specified	Not specified	
Środoń (1948)	Chornohora Mts. and Chyvchyns'ki hory Mts.	Beech (a), Spruce and Swiss pine (b)	~1200 (a) ~1650 (b)	8	Not specified	Not specified	
Rubner (1953) after Holtmeier (2009)	Tatra Mts.	Spruce, Swiss pine		6-8	Low density	Not specified	
Somora (1958, 1969)	Slovakian Tatra Mts.	Spruce, Swiss pine, Larch	~1700	8	Low density ~0.4	Not specified	Promoted the name *Waldgrenze*
Jeník & Lokvenc (1962)	Krkonoše Mts.	Spruce, Beech	~1300	5	Forest cover >0.5	>100	Proposed the criterion that the distance of isolated enclaves from a timberline does not exceed 100 m

Author	Location	Species	Altitude [m a.s.l.]	Minimal height of trees [m]	Extent of forest density	Area [m^2]	Others
Ellenberg (1963)	Alps	Spruce, Larch, Swiss pine	~2200	***	Low density 0.3-0.4	Not specified	
Plesník (1955 and subsequente publications)	Vysoké Tatry Mts., Belianske Tatry Mts., Malá Fatra Mts., Veľká Fatra Mts., Nízke Tatry Mts., Chočské Vrchy Mts.	Spruce, Larch, Swiss pine	~1350-1700	5	Medium density >0.5	>1000	
Geanana (1975)	Retezat Mts.	Spruce	~1615	5-6	Medium density ≥0.5	>250	
Zientarski (1985)	Tatra Mts., Karkonosze Mts., Babia Góra Mt., and Pilsko Mt.	Spruce	1050-1700	8	Low density ≥0.4	>1000	
Doležal & Šrůtek (2002)	Nízke Tatry Mts.	Spruce	1450	5	Medium density >0.5	>1000	Criteria adopted after Plesník (1971)
Kucharzyk (2006)	Eastern Carpathians	Beech (a), Spruce, and Swiss pine (b)	~1200 (a) ~1650 (b)	12 (a) 8 (b)	'Very dense' (a), low density >0.4 (b)	>1000 (b)	
Treml (2007); Treml et al. (2008)	Hrubý Jeseník Mts., Krkonoše Mts., Králický Sněžník Mt., Šumava Mts.	Spruce	1310	5	Medium density >0.5	>1000	Introduced the minimum width of forest patches as 10 m
Guzik (2008)	Tatra Mts.	Spruce, Swiss pine, Larch	1700	8	Low density ≥0.4	>1000	Criteria adopted after Sokołowski (1928) and Plesník (1971)

A specimen should be considered a tree if:
* in favourable habitat conditions it could develop into a tree form
** it is higher than a person
*** it is higher than the average depth of snow cover

exceed 30 m. The biggest differences concern the minimum forest cover to be called a forest: from 1 are (Jeník & Lokvenc 1962) to 1 hectare (Vincent 1933). The discrepancies are considerable and authors often fail to provide the adopted criteria and to justify their choices. For these reasons, the comparison and analysis of results is made difficult.

The secondary criterion to be taken into account is the tree species dominating in the forest above the eTE. During his research in the Tatra Mountains, Guzik (2008) excluded the community of *Athyrio-Sorbetum*, forests with mountain ash (*Sorbus aucuparia* L.) from this ecotone. Such an assumption can be applied only to the areas where the uppermost forest sections are clearly dominated by coniferous species and to areas which do not involve mountain regions where there is a beech timberline (e.g. Western Bieszczady (522.12), Połonyns'ki hory (522.2) and the Cernei Mountains in the Godeanu Mountains (531.33 according to the regionalisation by Kondracki 1978).

The character of a dense forest boundary is also affected by the shape and type of the ecotone above it. Above the eTE, a forest thins out, while trees become crippled to increase their chances of survival (Paulsen et al. 2000; Körner 2012a). The upper boundary of trees (*tree species line*) can be distinguished (Fig. 2). The very notion of a 'tree' is also defined differently and its height is considered the main criterion. As Holtmeier (2009) claimed, according to numerous authors these are specimens with a height of from 1 to 8 m, depending on the species. Tree species reaching the uppermost areas remain crippled. The uppermost areas are the upper boundary of shrub-like trees (*krummholz-line*). Depending on the mountain region, krummholz-line term refers both, to plants whose growth course is determined by habitat conditions (e.g. winter forms) (Norton & Schonenberger 1984) and those whose growth course is conditioned genetically (e.g. *Pinus mugo* in Carpathians) (Holtmeier 1981; Grace 1989). The area between a dense forest and the upper boundary of trees is defined as the struggle zone (*Kampfzone*) (Däniker 1923). The interface of a varied width between the forest layer and the dwarf mountain pine layer is called a timberline ecotone (Troll 1972; Tranquillini 1979; Slatyer & Noble 1992; Holtimeier 2009).

Timberline fluctuations during the Holocene

Depending on the climatic conditions, in the Holocene a timberline went through several regressive and progressive phases. Palynological research from the Alps (Wick & Tinner 1997; Carcaillet & Brun 2000; Van der Knaap et al. 2000; Wick et al. 2003) confirms that the timberline reached its uppermost location in the Mid- to Late Holocene (6,000 – 3,500 BP

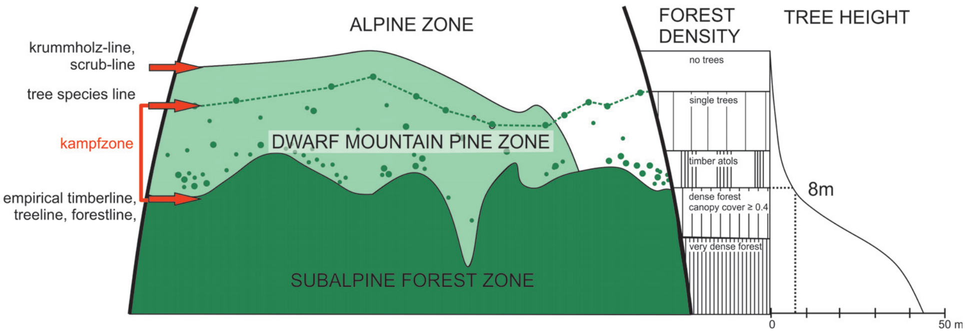

Figure 2. The transition-area model in the mountain environment of a temperate climate together with the criteria for timberline delineation

Source: based on Sokołowski 1928; Holtmeier 2009; Körner 2012b in the Northern Alps, 8,000 – 5,000 BP in the Central and Southern Alps). While in the Western Carpathians, the Tatras (Obidowicz 1996), and the Żywiec Beskids (Obidowicz 2003, 2004) the timberline reached its highest range (in the Tatra Mountains up to the height of 1700 m) later, in the Older Subboreal period (3,000-2,000 BP). From that time, the range of the timberline lowered until the end of the 'Little Ice Age' (~1850), while since the Bronze Age (~3,400 BP), the structure and location of the timberline have been strongly affected by human activity. The natural, climate-change-related fluctuations of the timberline's range in the Holocene did not exceed 200 – 300 m (Carcaillet & Brun 2000; Wick et al. 2003). In the last century of intensive human interference, changes in the location of the timberline have been observed in many mountain massifs in the world (Wieser & Tausz 2007). Nowadays, in the age of global climate warming, another phase of a forest ascending higher altitudes is expected. However, the scale of these changes may be intensified or, on the contrary, slowed down and hindered, due to the centuries-old human impact on the high-mountain environment.

The stability of a geosystem and a possible disturbance of the balance depend on two variables:

- the type, spreading potential, intensity, and frequency of the occurrence of the stimulus affecting the geosystem,
- the sensitivity and susceptibility of the natural environment, i.e. its inclination to succumb to such stimuli – its internal features (Turner 1988; Kistowski 2000; Balon 2001).

In the natural or semi-natural environment, the stability of the environment decreases with the increase of the altitude a.s.l. and slope inclination, but determining such a simple relation in the human-disturbed environment is impossible (Balon 2007).

The system's stability is understood in two ways:

- as its durability in the unchanged environmental conditions, but also,
- as its ability to return to the state resembling the original one after the exposure to the disturbing external factors has finished (Richling & Solon 1996; Balon 2007).

The durability in the unchanged environmental conditions can be narrowed to a particular time span. Then, the system's permanence must be dealt with, which is the best expression for nature systems (Malinowski et al. 2004). Orographic, soil and anthropogenic barriers, and most of all, a climatic barrier, constitute major elements stabilising a timberline location (Hess 1965).

Natural environmental factors shaping the course of a timberline in the Northern Hemisphere

In the existing studies on timberlines, most attention is paid to the direct cause of vegetation boundaries in the mountains, i.e. the reaction to stress factors: abiotic and biotic ones (research in the Alps: Brockmann-Jerosch 1919; Troll 1973a; Körner 1998).

There are numerous review studies on the timberline (Grace 1989; Körner 1998; Jobbágy & Jackson 2000; Holtmeier & Broll 2007; Wieser & Tausz 2007; Holmeier 2009; Körner 2012b). These studies focus on the importance of the climate as a restricting factor (in a timberline ecotone) and preventing the growth of trees (above the timberline). According to research, the potential location of a timberline corresponds to the course of:

- an annual isotherm of 2°C (the Tatras: Hess 1965);
- a vegetation period isotherm of 5.5°C – 7.5°C (the Venezuelan Andes: Walter & Medina 1969; the Alps: Hoch et al. 2002; worldwide timberline: Körner 2012b);
- a 10°C isotherm of the warmest month (mountain regions in North America: Daubenmire 1954; Fennoscandia and the Alps: Holtmeier 1974).

The average temperature of the coldest month affects the type of vegetation adjacent to a timberline (worldwide timberline: Jobbágy & Jackson 2000). The microclimate to which a given plant is exposed, for example, soil temperature exposure, is also important (worldwide timberline: Körner

& Paulsen 2004). It has been pointed out that in humid mountain regions, the average soil temperature is significant. The minimum average soil temperature value during the vegetation period should reach 6.7°C ± 0.8°C (worldwide timberline: Hoch & Körner 2003). Körner (1998), and others, think every tree species has a minimum temperature below which growth processes are slowed down or entirely stopped. This hypothesis was confirmed in the Italian Alps by Rossi et al. (2007). They determined the xylem activity threshold, when the average daily air temperature amounts to 5.6°C – 8.5°C, and the average trunk temperature is 7.2°C – 9.0°C (depending on the tree species). It has also been found, that the occurrence of very low temperatures, which do not pose any threat to a timberline as such, may damage plants directly and contribute to growth distortions resulting from partial damage (the Alps: Tranquillini 1979; Larcher 1985). Additionally, the role of solar radiation rises with altitude to balance the lower and lower air temperature (Wilczyński 2004).

The altitude of the timberline in the Northern Hemisphere is inversely proportional to the latitude at which it is located (Troll 1973b; Wardle 1974; Arno 1984; Körner 1998; Holtmeier 2009). This relationship is connected with the evident mechanism of the increasing warmth deficiency going from the Equator to the Poles (Cogbill & White 1991; Jobbágy & Jackson 2000). The relationship is not a linear interdependence. In circumpolar regions the location of a timberline drops drastically in the Southern Hemisphere and occurs 1000-1500m lower than in the Northern Hemisphere (Körner 1998). Research proves that continental climate provides favourable conditions for a forest to be located at higher altitudes (Siberia and the Himalayas: Malyshev 1993; Fang et al. 1996; Malyshev & Nimis 1997).

In mountains with moderate humid climates, air temperature, but also the sum of precipitation and the humidity of the environment play an important role in the position and condition of the timberline ecotone (Śląski Beskids: Feliksik & Wilczyński 2000). High precipitation during the summer has a negative effect on the condition of trees because cloudiness and rainfall lower air temperature (Wilczyński & Gołąb 2001).

Such factors as the occurrence of snow and wind activity are closely related to the climate. The thickness and duration of snow cover affect a timberline to a considerable extent. A prolonged period of snow cover shortens the vegetation period and reduces plant resistance. Large amounts of wet, heavy snow result in the creation of snow caps, which break branches or even entire trees (Grace 1977). On the other hand, snow cover can also protect plants against the destructive activity of strong wind, physiological draught and parasitic fungi (the Alps: Däniker 1923; Schröter 1926; Donaubaur 1963; Holtmeier 1974; Tranquillini 1979; Aulitzky & Turner 1982; Larcher 1985). Wind has an impact on evapotranspiration and the reduction of snow cover (Larcher 1985; Havranek 1993). Wind can also result in the formation of specific flagged krummholz of tree crowns (Holtmeier 1996). Cold winds increase the penetration of low temperatures and frost into the soil, which causes physiological drought (worldwide boreal forest: Bonan 1992). Weakened stands in valley narrowings are most susceptible to the destructive impact of wind activity (the Tatras: Kotarba 1970). However, wind helps transport seeds upslope – anemochory (Siberia: Shiyatov 1966; Havranek 1993).

Apart from the most frequently discussed climate-related factors, other environmental components which influence the location and nature of a timberline have been determined. There are numerous classifications which can be generally divided into groups according to: physiological factors, landform features, lithology, morphogenetic processes, biotic factors, and anthropogenic influence (the Polish Carpathians: Jodłowski 2007).

Physiological factors are strongly related to climatic and weather conditions. They include physiological drought, i.e. tree dehydration caused by extracellular freezing of water (Research in the Alps: Larcher 1985; Tranquillini 1976, 1979, 1982; the Sierra Nevada Mountains: Sowell et al. 1982; New Zealand's and Australian Mountains: Sakai & Larcher 1987; the Alps: Havranek & Tranquillini 1995). In the Western Carpathians the problem becomes most serious in spring at sunny southern slopes, where the soil is still frozen but strong radiation stimulates the trees to grow (Wilczyński 2004).

Interspecies competition for access to light, water, and mineral elements constitutes a biotic element (Tatra Mountains: Sokołowski 1928). With a rise in altitude, it becomes less likely for a sapling to take root successfully above a timberline. Problems with rooting may be affected by the lack of vital diaspore (New Zealand's Mountains: Norton & Schonenberger 1984; Scotland: Grace & Morton 1990).

It is thought that a zero production of organic matter caused by an unfavourable climate, is one of the elements which control forest location (the Alps: Boysen-Jensen 1949; Stevens & Fox 1991; Slatyer & Noble 1992; Glacier National Park, USA: Cairns 1998; Cairns & Malanson 1998). To date, though, no further research has found a connection and confirmed this hypothesis (New Zealand's Mountains: Wardle 1971; North America Mountains: Ives 1978; Arno 1984; Holtmeier 2009).

Mycorrhizal fungi decompose organic matter and enable trees to absorb microelements (mostly phosphorus, nitrogen, but also zinc and copper, as well as the plant hormones: auxin, gibberelin and cytokonin). These fungi play an important role in the circulation of nutrients in the timberline ecotone soils. Fungi are thought to act as a buffer and an emergency container of nutrients (Read & Perez-Moreno 2003). Mycorrhiza helps trees to resist harsh climatic conditions and helps trees advance to higher altitudes (Read 1998). All trees growing in the timberline ecotone are mycorrhizal (the Canadian Mountains: Kernaghan & Currah 1998; Kernaghan 2001; worldwide review: Haselwandter 2007). Mycorrhizal fungi help young saplings to take roots in a timberline (North American Mountains: Hasselquist et al. 2005). In the harsh high-mountain environment, cooperation between organisms is more important than interspecies competition (North American Mountains: Callaway 1998).

The altitudinal timberline location is highly dependent on landform features and topography. Research on this subject describes the mass-elevation effect (mountain-mass effect, massenerhebungseffekt, Merriam effect) (the Alps: Di Quervain 1904; Brockmann-Jerosch 1919; Tollner 1949) connected with the continental effect. The larger the massif is, the higher the plant and climatic zones are located. Additionally, the closer to the massif centre, the more intense the effect is. For example, in the central part of the Austrian Alps, the vegetation period is 80 days longer compared to the external ranges (Turner 1961). During his research on the snowline in the Alps, Di Quervain (1904) came to the conclusion that the snowline was located higher within the Alpine system (the Central Alps) than in the surrounding Eastern and Western Alps. For many years the mass-elevation effect was forgotten and disregarded in the studies on timberlines (Hermes 1955; Körner 1998; Jobbágy & Jackson 2000).

Slope exposure and inclination constitute the main determinant in microclimate changes and, consequently, flora distribution (the Alps: Geiger 1961; the Tatras: Plesník 1971). The amount of radiation that reaches the surface depends on the landform features. The differences in the radiation amounts are reflected in: the soil and air temperature variations, the duration of snow cover, and soil humidity (the Alps: Barry & Van Wie 1974; Larcher 1985; the Italian Alps: Turner 1993). It has also been observed that upper river-valley sections influence the timberline lowering. Such an influence is the so-called 'valley phenomenon' (Fries 1913). This phenomenon takes into account the combined effect of the activity of thermal (lower heating), orographic, and economic factors (the Tatras: Kotula

1889-1890; Sokołowski 1928; Hess 1965). Diversified landform features, such as cliffs, rock walls or crags, constitute a barrier for forest development. On the other hand, these features act as protection from destructive human activity (the Polish Carpathians and the Fenoscandia: Balon 1995).

These factors and the type of substratum where particular plant habitats occur, have an indirect impact on the soil typology. The bedrock that soils originated from decide the soil typology.

Depending on the bedrock and its susceptibility to erosion processes, which occur in a time unit, soils of various soil profile depth and diverse physical and chemical features may be created (Dobrzański 1995). Considering these factors, soil can be considered one of the most complex elements of the natural environment which affect a timberline ecotone. Among the features which affect the course of a timberline ecotone are such soil parameters as: pH, grain composition or sorption properties, as well as groundwater level and their ionic composition, which also influence the accumulation of organic matter (Nicia 2009; Heckman et al. 2009).

There is not much research into ecotone zone soils. The majority of the research which has been done concerns the Alps (Friedel 1967; Bednorz 2000). It was indicated that substratum built of quartzite rocks contributes to a timberline lowering. The biggest differences in the eTE course were observed when comparing carbonate and carbonate-free rocks (the Tatras: Sokołowski 1928; Myczkowski 1955a; Plesník 1956, 1967, 1971; the Alps: Arno 1984). These rocks are susceptible to erosion, and consequently, prone to the formation of soil cover. The thickness of soil cover in a timberline ecotone is also connected with the inclination of slopes and erosion processes occurring in the surface soil layer. Soils which appear on slopes with smaller inclines, where the intensity of erosion processes is lower, are characterised by thicker soil profiles. The surface organic and mineral layers, as well as the depth of the entire soil profile are thicker (Musielok et al. 2013).

The occurrence of violent geomorphological processes (snow and stone avalanches, rockfalls, debris flows, debris and mud flows, lahars) is related to the landform features. In a typical high-mountain environment, the initial avalanche zone and the debris flow failure zone start in the morphogenetic periglacial (cryonival) system. The avalanche activity has a direct or indirect influence on a temperate forest system (the Tatras: Kotarba & Starkel 1972; Kotarba et al. 1987; Rączkowska 2007). The smaller the slope inclination and the farther the distance between the timberline and peaks, the smaller the range of timberline affected by these processes (Holtmeier 2009). The location and structure of a forest reflect the area's topography and landform features. A forest occupies convex landforms, while concave ones constitute the flow paths of, for example, avalanches. A forest reaches its uppermost location in the areas unaffected by avalanches – in small valleys of gentle slopes (Holtmeier 1974). A spruce (the most prevalent species in the timberline ecotone in the Carpathians) is a tree with an extensive but shallow root system, which makes it less resistant to morphogenetic processes. Trees growing on the edge of avalanche runout zones often suffer mechanical injuries. The overall condition of these trees is adversely affected by the injuries (Myczkowski 1955a; Stoffel et al. 2010). The content and structure of stands located within the range of avalanches alter diametrically. The bottom of the avalanche runout sector is dominated by species which are more flexible and more resistant to mechanical injuries and to a thick, long-lasting snow cover (*Pinus mugo, Alnus* Mill., *Sorbus aucorparia,* Salix L., *Betula* L.) (Canadian Mountains: Johnson 1987).

The influence of anthropopressure on the timberline in the Carpathians

People have affected and transformed their surroundings for over 5500 years. For the last 200-300 years the influence has intensified (worldwide studies: Goldewijk 2001). At present, there are only 280,000 hectares of natural or semi-natural forests of the upper wooded section left in the Carpathians (WWF 2001). In the high-mountain areas, human activity in the timberline has involved degradation of the environment through ore mining and metallurgy, sheep and cattle pasturing, and forest clearing for the production of charcoal. The outbreaks of secondary pest (e.g. spruce bark beetle), are a direct effect of the draining of natural resources and weakening of stands. Tourism has also had an increased impact on forests (Jodłowski 2007).

Environmental pollution and pollution-related damage to vegetation is an indirect result of human activity (Unsworth & Fowler 1988). Pollution originally appeared with the rapid development of heavy industry in the middle of the 20th century in Central Europe. Sulphur oxides (SO_4 and SO_2) and nitrogen compound emissions, and the release-related acid rains mostly affected the forests in the Sudetes located in the so-called 'black triangle' (Michaelis 1997; Danielewicz & Zientarski 2004). The Western and Eastern Carpathians were less affected by air pollution and pollution-related, acid rains. Since the main emission sources were distant and located on the windward side, the increased pollution in these mountain areas was smaller and occurred at a slower pace (Muzika et al. 2004; Fleischer et al. 2005).

In the last 50 years, reserve or strict protection measures have been implemented in many Carpathian massifs. As a result, the ecological balance in the high-mountain environment is being restored and reforestation is proceeding. The Carpathian Convention is a framework agreement for establishing cooperation and comprehensive policy for the protection and sustainable development of the Carpathians, was started up in 2003. It contributed to the establishment of the Carpathian Network of Protected Areas (CNPA) in 2006. Currently, 18% of the Carpathian area is under protection. There are 285 protected areas, including 36 national parks (Fall 2007).

Research on the timberline ecotone in the Carpathians

The oldest scientific studies on a forest height range, date from over 200 years ago and concern the Alps (e.g. Hacquet 1779; Zschokke 1804; Sendtner 1854; Kerner 1864/1865 after Holtmeier 2009). Forest ranges in the Carpathians were mapped out in the second half of the 19th century (Janota 1866; Zapałowicz 1879, 1889). Systematic research began with the studies of Imhof (1900), Marek (1910) and Brockmann-Jerosch (1919). Until the beginning of the 20th century, except for one study on the timberline in the Schwarzwald (Drude 1890 after Holtmeier 2009), the alpine regions were the only mountain regions studied in Europe. Since the 1920s, systematic and comprehensive research on timberlines has been conducted all over the continent. However, no other mountain region has as extensive a collection of scientific studies on this subject as the Alps.

The most important results about the timberline in the Carpathians have been collected in Table 2. The first study on the Carpathians by Fekete & Blattny (1913-1914) is a monographic delineation of altitudinal ranges (maximum and average) of particular tree species and vegetation layers (for different exposures) in the former Austro-Hungarian Empire. This study contains tabular lists without detailed explanatory notes or descriptions of the research methodology.

The timberline in the Tatras (514.5) has been the centre of attention since the beginning of research in the Carpathians. The studies were initiated by the following researchers interested in the Tatras: Janota (1866) and Sokołowski (1928), Myczkowski (1955a, 1955b, 1964), Fabijanowski (1955), Zientarski (1985) as well as the Czech researchers and Slovakian researchers: Vincent (1933), Svoboda (1934), Somora (1958, 1969), and Plesník (1967, 1971, 1973). Recently, the empirical timberline in the Tatras was examined by Guzik (2008), while its dendrochronological condition was studied by Czajka (2010) and Kalafarski (2011), and the geomorphological condition was studied by Kotarba (1996).

Table. 2. Summary of key results of the timberline research in the Carpathians (not including the research carried out in the massif of Babia Góra, which are described in a separate chapter)

Author (year)	Study area	The most important results
Janota (1866)	Tatra Mts.	Specifies the altitudinal ranges of individual species of trees, including *Pinus cembra, Picea abies,* and *Pinus mugo.*
Zapałowicz (1879, 1889)	Babia Góra Mt., Pokuts'ko-Bukovins'kì Karpati Mts.	He described the average altitude of the timberline (using a barometer) throughout the massif and the detailed altitude of the timberline in a few important places.
Fekete & Blattny (1913-1914)	Mountains of the former Austro - Hungarian Empire	A tabular summary of the max., mean, and min. altitudinal ranges of each species with the division based on slope exposure. Distinguished *timberline* and *treeline* providing rules for their determination (Tab. 1).
Sokołowski (1928)	Tatra Mts.	Apart from specifying clear methodology for timberline marking, connected timberline occurrences with ecological conditions – environmental factors and anthropogenic impact. Moreover, he observed the influence of mass-elevation effect and "valley phenomena" on a timberline. He established the definition of empirical upper timberline.
Kubijowicz (1926, 1927)	Eastern Beskids, Żywiec Beskids	History of the pasturing in the studied areas, together with quantitative information about cattle and sheep grazing. Description of the beginning of the clearing above and below the TE. A brief mention of the impact of grazing on the environment.
Jakób (1937)	Gorgany Mts.	A study on the impact of environmental factors on the timberline. The wind caused TE lowering. He drew attention to the need to protect the stone-pine forests which were heavily used.
Środoń (1948)	Chornohora Mts. and Chyvchyns'Ki hory Mts.	A study on the human impact on the formation of 'Poloninas' (clearings on top of the mountains ends with beech timberline). Denies the claims that the beech timberline is natural.
Somora (1958, 1969)	Slovakian Tatra Mts.	Altitudinal ranges of timberline in the Liptowskie Tatras with clear methodology (Tab. 1).
Myczkowski (1955a, 1955b, 1956, 1962)	Polish Tatra Mts.	Short popular-science articles describing the entire spectrum of the types of TE in the Tatras. A case study in the Mała Koszysta massif (with emphasis on the effects of wind) and in Rybi Potok Valley (climate impact, avalanches, and interspecific competition).
Plesník (1955, 1956, 1957, 1958, 1966, 1967, 1971, 1973, 1978, 2002)	Vysoké Tatry Mts., Belianske Tatry Mts., Malá Fatra Mts., Veľká Fatra Mts., Nízke Tatry Mts., Chočské Vrchy Mts.	A series of monographic studies on the functioning of the TE in the Slovak Carpathians. Described the most important factors that modified the TE in all massifs; extensive use of current knowledge.
Zarzycki (1963)	Western Bieszczady Mts.	Research on the history of the creation of 'Poloninas'. Author concluded that TE in the Bieszczady is reduced by 100-200 m in relation to the natural state.
Geanana (1972, 1975, 1991, 1996, 2004)	Retezat Mts., Romanian Carpathians	Studied the effects of altitude, soil cover, and the mass-elevation effect of the location of the timberline in the Romanian Carpathians, with particular emphasis on the Retezat Mts.
Zientarski (1985)	Tatra Mts., Karkonosze Mts., Babia Góra Mt. and Pilsko Mt.	Confirmed the influence on the course of the mass-elevation effect on the timberline, and studied the impact of natural and artificial factors.

Author (year)	Study area	The most important results
Kotarba (1996)	Tatra Mts.	Author separated geocomplexes in the alpine environment, which are extended versions of the climate zones, containing geomorphological aspects.
Gubka (1996), Gubka & Pittner (2013)	Nízke Tatry Mts.	Ecological considerations on the condition of spruces growing on the TE depending on the altitude and exposure - case study.
Kucbel (2001), Seben (2005)	Nízke Tatry Mts.	Development of forest sciences for the best selection of quality spruce seedlings to artificial plantings around the slopes threatened by avalanches.
Doležal & Šrůtek (2002)	Nízke Tatry Mts.	The study of changes in the structure and composition of plant communities in conjunction with the soil and snow along the altitude transect (including also the TE). The timberline altitude was set at 1420-1510 m a.s.l. Altitude explains 35% of variation in the forest.
Kucharzyk (2006); Kucharzyk & Augustyn (2008); Augustyn & Kucharzyk (2012)	Eastern Carpathians	Analysis of the TE changes in the Eastern Carpathians based on aerial photography and digitalisation of cadastral maps and Josephine and Franciscan Metrics from XVII / XVIII. Over the past 150 years, the beech timberline in the Western Bieszczady is practically stable (mean altitude increase 10m). Indicates differences in the ecology (resistance and resilience) of beech and spruces, conditioning the different nature of the TE.
Mihai et al. (2006, 2007)	Bucegi and Iezerul Mts.	Based on aerial photographs from 1990 and 2000 taken in Bucegi Mt. they observed regeneration of beech forests and deforestation of mountain shrub pine caused by grazing. In turn, in the Iezerul Mts. from1886 to 2002, they observed a timberline altitude increase, the replacement of coniferous forests by mixed forests, and a natural regeneration of beech trees.
Török-Oance et al. (2006)	Făgăraş Mts.	Investigate the naturalness of the TE by comparing it with an annual 3^{0}C isotherm.
Rob & Taut (2007), Rob (2008)	Gutâi Mts.	According to the authors, the upper limit of beech in Gutâi massif (1442 m a.s.l.) is a natural limit (identified on the basis of forest density, and tree shapes).
Kern & Popa (2008)	Călimani Mts.	Dendrochronological study of *Pinus cembra*. They found a 65 meter upward migration at the treeline. Produced a hypothesis about the decrease of frost associated with global warming, which would reduce stress in the timberline ecotone.
Guzik (2008)	Tatra Mts.	Photo interpretation and remote sensing analysis of the functioning of the recent timberline and the environment above it. Indicates the maximum and minimum ranges of the forest, confirmed the impact of a mass-elevation effect and the "valley phenomena". The timberline changes between 1955 and 2004 were conducted in the Polish Tatra Mts.
Sitko & Troll (2008)	Western Chornohora	Interpretation of recent and historical maps (scale 1 : 100,000). Observed the altitude timberline increase of 80 m between 1933 and 2001. Area above the timberline shrank by 30%. The biggest changes are associated with spruce forest far away from working livestock farms. The lowest changes are connected with deciduous timberlines near the farms.

Author (year)	Study area	The most important results
Kricsfalusy et al. (2008)	Ukrainian Carpathians	Reconstruction of timberline changes based on 1852-1964 maps and LANDSAT images. (Extensive article but without citation and clear methodology).
Kuemmerle et al. (2009)	Ukrainian Carpathians	Forest cover changes between 1988 and 2007 based on LANDSAT images. Illegal logging had an impact on forest cover. The forest cover decreased in the central part of the region.
Czajka (2010), Kalafarski (2011)	Polish Tatra Mts.	The authors analysed the timberline changes in the last 50 years (Guzik 2008) and provide a dendrochronological examination of progressive and stable timberlines of different types (anthropogenic, edaphic, and climatic). Significant differences in the conditions and age structures of the spruce forests confirms their different origins.
Martazinova et al. (2011)	Ukrainian Carpathians	Analysis of treeline changes affected by recent climate changes. The coniferous treeline increased at higher altitudes in contrast to the deciduous treeline which was stable or decreased. Those changes were not related with climate change.
Kucsicsa (2011, 2013)	Rodnei Mts.	Photo interpretation analysis of satellite images as a source of information about timberline changes. Particular attention was paid to the human influence.
Török-Oance R. & Török-Oance M. (2012)	Tarcău Mts.	Case study based on the LANDSAT satellite images and historical maps (1950s), where the timberline changes were analysed. The changes were associated with the termination of grazing 20 years ago.
Knorn et al. (2012)	Romanian Carpathians	The authors examined the effectiveness of protected areas in Romania, with the help of LANDSAT satellite images from the 1995-2005 period. It was found, that the loss in protected forests is even greater than in the adjacent regions. The national parks effectiveness of biodiversity protection decreases.
Tanase (2013)	Giumalău Mts.*	Used historical maps (scale 1 : 100,000) and LANDSAT images to detect timberline / treeline changes during last 150 years. The timberline increased about 113 m to almost 1550 m a.s.l. (There is a lack information about methodology.)
Shandra et al. (2013), Weisberg et al. (2013)	Carpathians*	Changes in TE ecotone in the last 130 years on the basis of historical maps and LANDSAT images the forest cover increased were observed in timberline ecoton (34% of all afforestations). The impact of global warming and land use were analysed. The changes in timberline altitude are related with: slope steepness, shrub cover above it, elevation and distance to sheds.
Griffiths et al. (2014)	Carpathians *	Remote sensing analysis of land covers changes change during six, five-year periods from 1988 to 2010. Automatic classification was used for the entire Carpathian Mountains. The share of mixed and coniferous forest were shown to have especially decreased, while deciduous forest increased. The results indicated that forest cover has likely increased locally, due to abandoned agriculture or afforestation policies. Almost 20% of the forests in the study area experienced disturbances.
Munteanu et al. (2014)	Carpathians *	Meta-analysis of land-cover changes over the past 250 years in the Carpathians, based on 66 existing papers. Forest cover changes were dependent on the political situation and the changes taking place in agriculture.

* Analysis of a part of the mentioned region

The research in the Slovakian Carpathians: the Malá Fatra Mountains, Veľká Fatra Mountains, Nízke Tatry Mountains, and the Chočské Vrchy Mountains (514.4, 514.53, 514.8, 514.9) was conducted by Plesník (1955, 1956, 1957, 1958, 1966, 1978). More recently, research was done concerning the restoring of spruces below the timberline in the Nízke Tatry Mountains by Gubka (1996), Gubka & Pittner (2013). Numerous works by Slovakian researchers have been botanical studies on the alpine layer vegetation (Doležal & Šrůtek 2002) and studies in the range of forest sciences, dealing with restoration and planting in a timberline ecotone (Kucbel 2001; Seben 2005).

The issue of timberline in the contemporary Ukrainian Carpathians and the Western Bieszczady Mountains (522 and 523) was widely discussed by Polish researchers until the mid-20th century (until the change of state boundaries). The research work was carried out in Pokuts'ko-Bukovins'kì Karpati Mountains (522.16, 523.1) (Zapałowicz 1889), in the Chornohora Mountains (522.25) (Wóycicki 1930; Środoń 1948), in Gorgany Mountains (522.15) (Jakób 1937), and in Chyvchyns'ki Hory Mountains (a range of the Maramureşului Mountains 523.1) (Środoń 1948). The impact of grazing on the environment of the Eastern Beskids was examined by Kubijowicz (1926). Most research in this region focuses on the lack of the upper spruce section and the reasons for this lack, in the Lesiste and Poloninskie Beskids (Kubijowicz 1926; Środoń 1948; Zarzycki 1963; Zientarski 1985). In the last few years, the research has concentrated on the timberline changes since the mid-19th century with regard to post-socialist transformation and contemporary climatic changes – in the Ukrainian Carpathians (Kricsfalusy et al. 2008; Kuemmerle et al. 2009; Martazinova et al. 2011; Baumann et al. 2011), in the Western Bieszczady Mountains (Kucharzyk 2006; Kucharzyk & Augustyn 2008; Augustyn & Kucharzyk 2012) or in the Western Chornohora Mountains (Sitko & Troll 2008).

The timberline in the Romanian Carpathians is the least known one. Geanana was the precursor of the research on the timberline in this region. He studied the impact of the altitude and mass-elevation effect, on the location of the timberline (1972, 1975, 1991, 1996, 2004) in the Retezat Mountains (531.32). Cenuşă (2000) carried out studies on forest ecology in its uppermost ranges. In the Făgăraş Mountains (531.15) the timberline positions were compared to the annual isotherm of 3^{0}C (Török-Oance et al. 2006). The influence of human activity in part of the Ţarcu Mountains was analysed as well (Török-Oance R. & Török-Oance M. 2012). There are also studies on the timberline in the Rodna Mountains (523.3) (Kucsicsa 2011), in the Gutâi Mountains (523.56) (Rob & Taut 2007; Rob 2008) and in the Giumalău Massif (523.42) (Tanase 2013), however, these studies were quite superficial and the authors did not present the methodological assumptions they had made in their work.

Aerial photographs are widely used as sources of information in the research on environmental changes. The photos have been used to show changes which have occurred in the last 150 years since aero-photography developed. Photo interpretation of multitemporal aerial images may be applied extensively in the studies on the succession of biocenoses, the activity and changeability of geomorphological processes (Van Westen & Getahun 2003), forest cover transformations (Fensham & Fairfax 2002; Paterek & Olędzki 2005), krummholz zone regeneration (Švajda et al. 2011) or timberline changes (Luo & Doi 2013). Plesník (1973) was one of the first researchers to use aerial photos as a source of information on the changes of timberline location in the Carpathians. Nowadays, the method has been used by M. Guzik (2008) in the spatial research on changes in the timberline ecotone of the Tatra Mountains. Stereographic aerial photographs constituted the basis for the development of the method of repeated terrestrial photography. This method was employed in the studies on forest cover changes in the Tatra Mountains (Kolecka & Kaim 2010). Modern techniques and the development of satellite technologies made it possible to conduct large-scale analyses of forest cover changes (in the last 30 years) with the application of LANDSAT (and the latest projects) imaging in the entire Carpathians (Griffiths et al. 2014), the provinces (the Eastern Carpathians: Kucharzyk & Augustyn 2008) as well as in particular massifs: Buzău Mountains (525.2) (Malek et al. 2014), the Iezerul Mountains (531.14) (Mihai et al. 2007), in the Făgăraş Mountains (531.15) (Osaci-Costache &Ene 2010), the Bucegi Mountains (531.14) (Mihai et al. 2006), in the Rodna National Park (Knorn et al. 2012; Kucsicsa 2013), in the Marmarosh National Park, and the Călimani Landscape Park (Knorn et al. 2012), which are indirectly affected by the timberline problems. Comparative analyses of land development on historical and modern maps have a lower accuracy (1 : 75,000 or 1 : 100,000 scale) (Sitko & Troll 2008; Kricsfalusy et al. 2008). However, the historical and modern maps are often characterised by a longer timespan: reaching to about 150 years back.

There are only four studies on the timberline for the entire Carpathians. One of the studies is a monograph from 100 years ago (Fekete & Blattny 1913-1914), another study is a synthetic picture by an American and Ukrainian team of researchers (Shandra et al. 2013; Weisberg et al. 2013), and another is a description of the influence of global factors on the timberline position (Czajka et al. 2015b). Some fragments of the Carpathians massifs were not examined. For example, the southern slopes of the Southern Carpathians which were outside the former Austro-Hungarian Empire, were studied in only one of them. A meta-analysis drawn up by a team of American, Polish, Ukrainian, Slovakian, Hungarian, and Czech researchers constitutes an important study on the forest cover changes in the Carpathians (Munteanu et al. 2014).

Research on the forest in the subalpine zone on the Babia Góra Mountain

The subalpine forests and the timberline in the Babia Góra National Park have been examined thoroughly (Walas 1933; Celiński & Wojterski 1961, 1963, 1978; Holeksa 1998; Kasprowicz 1980; Fabijanowski & Gądek 1983; Zientarski 1985; Awzan et al. 1986-1987), however, there is not enough data from the Slovakian part of the massif (Vorčák et al. 2006b), and especially comprehensive studies on the whole massif (Tuček et al. 2004). Owing to their semi-primeval character, the uniqueness of the Babia Góra forests has been discussed by almost all researchers interested in this region (Szwagrzyk et al. 1996, 1997). They may constitute an excellent reference point in assessing the natural character of other forest areas. However, it has been pointed out that biocenoses transformed in the past, and currently undergoing a process of spontaneous renaturisation, are not uncommon here (Holeksa et al. 2004).

The timberline ecotone mainly consists of Norway spruce *Picea abies* (Jaworski & Kaczmarski 1989, 1995) with mountain-ash *Sorbus aucuparia* (Borysiak 1974, 1985). Several authors have also examined the issue of the Babia Góra spruce forest age structure (Zientarski 1976), concluding that there is a shortage of young specimens (under 80 years) and specimens older than 200 years. The oldest specimens reach the age of 360 (Bednarz et al. 2002), or even 400 years (Czajka unpublished data).

The first notes on the vegetation and layer character of Babia Góra were made by Staszic (1815) in the first half of 19th century. Zapałowicz (1879) was the first researcher who conducted a systematic study on the subalpine forest, and in particular, on the timberline in this region. He described the ranges of particular plant species and determined the uppermost range of the spruce forest timberline. Anthropogenic and natural factors affecting the timberline were studied by Kasprowicz (1980) and Zientarski (1985, 1989). There are no such studies for the Slovakian section of this part of the massif and no analyses of the timberline changes throughout the last century.

Zientarski (1976), Awzan et al. (1986-1987), and Vorčák et al. (2006a) carried out research on the changes of the stand structure and density, and the changes of spruce morphology with the increase of altitude in the Polish and Slovakian part of the massif. In harsh environmental conditions, generative reproduction is strongly limited. Thus, vegetative reproduction from roots and branches of older specimens predominates. This problem was examined in the Slovakian part of the massif by Vorčák & Jankovic (2009). Changes in temperature are the most significant factor differentiating stands in a vertical profile (Czajka 2012).

The history of economic exploitation of forests together with the grazing management had been discussed (Kubijowicz 1927; Zabielski et al. 1969, Jostowa 1972; Dzięciołowski 1963), but the data is fragmentary and synthetic analyses were impossible.

Conclusions and research needs

1. The Norway spruce (*Picea abies* L. Karst) or the European beech (*Fagus sylvatica*) are the main forest forming species of the Carpathian timberline. These species have different ecological demands, spatial patterns, and sensitivity to environmental changes. The beech timberline is more stable: its course in the Western Bieszczady Mountains has moved by only 10 m in the last 150 years. In the case of the spruce timberline, its succession and expansion into higher altitudes has been observed in many location in the Carpathians: in the Western Chornohora Mountains the spruce timberline has shifted upslope by 80 m in the last 70 years.
2. The natural, undisturbed location of a timberline depends on climatic factors, especially temperature. The climatic limit for the dense forest of the upper wooded section is defined in various ways – it corresponds to 10°C isotherm of the warmest month, among other things. However, as much as 95% of the timberline course in the Carpathians runs below the climatic limit determined in such a way.
3. Despite temperature, the distance of a particular massif from the Poles and the massif's mass-elevation effect are global factors which affect the timberline. In the Carpathians, the average elevation of the timberline decreases by 70m with every degree of latitude, while the timberline's changeability within the macro-region results from the varied mass-elevation effect.
4. A number of local factors have an impact on the timberline course in the Carpathians. Among the most significant natural factors are: the occurrence, intensity and dynamics of violent geomorphological processes, and the local relief (its variation, exposition, and gradients). Other natural elements are of secondary importance, while the influence of physiological factors (the impact of physiological drought, mycorrhizal fungi or tree regeneration, and sapling survival etc.) has not been determined thoroughly enough yet.
5. Research indicates that factors which are variable in time (anthropogenic activity and climatic conditions) cause disturbances in the timberline environment. Stable environmental factors (invariable throughout a long period of time: microtopography, soil cover, etc.) are responsible for the timberline site patterns.
6. Nevertheless, throughout the centuries, human activity has had the biggest influence on the Carpathian timberline dynamics. Since the 12th century and the times of Wallachian colonisation, the anthropogenic activity has affected the timberline leading to a downslope shift of the timberline of even 700 m in some massifs. Pasturing and clearing – related pressure were most intense in the 18th and 19th century. In the 20th century, the downslope shift of the timberline increased owing to the growth of environmental pollution and the development of tourism. However, since the 1920s different forms of this ecotone

preservation have been introduced. The political and economic situation of the Carpathian countries at the end of the 20th century (the fall of communism and system transformation), led to abandoning pasturage, and increasing forest areas. As a result of these processes, 34% of the Carpathian timberline has shifted upslope to higher altitudes in the last 120 years.

7. The highest upper wooded section zone is divided and defined in various ways. Sometimes the authors do not define the applied terminology and in different articles the same term can be understood in a different way. This ambiguity refers to virtually all the terms regarding the final zone of the upper wooded section (timberline, treeline, forestline, tree species line). The authors of comparative analyses who employ available results of the research into this Carpathian zone, should consider and be aware of these differences.
8. The timberline was the subject of a lot of scientific research from the second half of the 19th century up to the 1970s. Further analyses have become more widespread since 2006. Nowadays this topic is widely discussed. With regard to geographic dimension it may be observed that there is a disproportion in the quantity and quality of existing studies between the Romanian Carpathians and the remaining massifs. Therefore, they constitute a significant potential for the studies on the environment of the timberline ecotone.
9. The perspectives of future scientific research into the Carpathian timberline are connected with the ongoing transformations of the timberline caused by contemporary climatic and athropopressure-related changes. The effect of climate warming within the timberline is concealed by the natural succession of a forest combined with the reduction of anthropopressure.

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