Soil Toposequence under Man-Planted Vegetation in the Krkonoše Mts., Czech Republic

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Abstract: Mountainous areas represent regions with specific soil cover pattern that is naturally given by an altitudinal gradient. The objective of our study was to describe the soil cover development on the altitudinal gradient under changed environment given by man-planted vegetation and acidification. The studied area is characterized by spruce monoculture planting that replaced the original broadleaf natural vegetation and high load of anthropic acidification. The common hypothesis considering the sequence of Dystric Cambisol-Entic Podzol-Haplic Podzol with increasing altitude was not proved. The results of our study indicate that the influence of spruce vegetation causes the occurrence of Haplic Podzols at low altitudes where the natural soil formation does not induce their development. Results showed that the vegetation type can overrule other altitude-related soil-forming factors. The conversion of natural broadleaf and mixed forests to spruce monocultures leads to the expansion of podzolization process to lower altitudes.

Keywords: altitude; Krkonoše Mts.; podzolization; toposequence; vegetation

Mountainous areas represent regions with specific soil-forming principles. The soil cover pattern is naturally influenced by the elevation gradient. A direct influence is due to topology and an indirect influence stems from the impact of other soil-forming factors such as climate, parent material and vegetation. Human impact on natural ecosystems must be considered as an important factor of soil formation that influences the soil development. A change in vegetation cover and production of anthropogenic acidification are the most significant forms.

The objective of our study was to describe changes in the soil cover morphology due to the soil cover development processes, altitudinal gradient and anthropically influenced environment in the Krkonoše Mts., a part of the Sudetes mountain region.

Soil cover development in mountainous areas under natural conditions

A toposequence of Haplic Podzols at high altitudes, Dystric Cambisols at low altitudes and Entic Podzols in transition of these two soils is characteristic of mountainous areas in Central Europe with boreal forest zones characterized by a humid and cold climate (e.g. Boháč & Nálevka 1971; Němeček & Tomášek 1983; Lundström *et al.* 2000a; Borůvka *et al.* 2005, 2007; Bonifacio *et al.* 2006).

Dystric Cambisols are characterized by weathering of the parent material without any further differentiation of the profile through the vertical movement of its components. The typical horizon sequence is: mor (O), surface horizon (A), cambic horizon (Bw) and parent material (C) (WRB 2006). Soil-forming environment providing very acid conditions leads to podzolization. Haplic Podzols are characterized by a light-coloured, weathered leached eluvial horizon (E), which contains less base cations, Al and Fe than the parent material. This horizon is underlaid by a dark-coloured (reddish-brown, dark brown, black) illuvial horizon containing accumulated organic matter (Bs1) and Al oxides with or without Fe (Bs2) (Mokma *et al.* 2003). The formation and downward transport of complexes of organic acids with Al and Fe are considered as processes explaining eluviation. The immobilization of the complexes forms an illuvial horizon (Lundström *et al.* 2000b). Entic Podzols, which are characterized by the sequence of 0-(A)-Bs-C horizons, develop under transitional soil-forming conditions between Dystric Cambisols and Haplic Podzols.

The main influence of the altitude is indirect; it acts through the influence of climatic conditions such as temperature, precipitation amount or thickness of snow cover or type of natural vegetation. The podzolization process is connected with wet (normally more than 800 mm/year of precipitation) and cold climatic conditions (Pelíšek 1966; Tomášek 2007). The amount of precipitation is important for transport movement through the soil profile in both vertical and lateral direction. The regular distribution of precipitation leads to more intensive Podzol development (Laffan *et al.* 1989). Seasonal freezing influences the transport of water and particles through the soil (Sveistrup *et al.* 2005). High snow cover protects the soil against freezing and enables better percolation (Lundström *et al.* 2000a).

The type of vegetation that is connected with the altitude profile influences the soil formation significantly. In general, Podzol development is favoured by coniferous forests and ericaceous shrubs (Lundström *et al.* 2000b; Titeux *et al.* 2002; Briggs *et al.* 2006). Andreux (1996) and Berger *et al.* (2002) showed a strong evidence that spruce acidifies soils by accumulating highly acidic organic matter that undergoes slow oxidation. Lundström *et al.* (2000b) found out that weathering is more intensive in spruce stands compared to beech stands. Beech forests or admixture of beech in spruce stands help to counteract acidification of the top soil (Mládková *et al.* 2005; Berger *et al.* 2006).

Anthropically induced changes of soil formation process

Anthropogenic activities changed the natural relationships of soil-forming factors mainly by changing the vegetation cover and by additional acidification of the environment in the past.

Anthropogenic activities can be divided into two categories of impacts in the area of the Krkonoše Mts. Firstly, it is acid deposition caused by industry; secondly, it is a change of natural forests to spruce monocultures for wood production.

Natural relationships between altitudinal zones and vegetation (forest types) were significantly changed. The typical sequence of beech forest at low altitudes, beech-fir forest at middle altitudes and spruce forest at high altitudes was transformed to the almost uniform spruce monoculture plantation all over the altitudinal gradient with a few exceptions with remains of natural-like forests.

Anthropogenic acidification can enhance the podzolization process (Lundström *et al.* 2000a). Natural soil acidification given by acid parent rocks, high precipitation and forest vegetation cover can be accelerated by anthropogenic deposition of sulphur and nitrogen compounds. The threshold of podzolization process can be easily reached due to the low buffer capacity of soils. In the Czech Republic, soil acidification and consequent Al release are a problem particularly under the forest cover in mountainous areas. The Krkonoše Mts. have been massively affected by acid precipitation in the last decades (Hruška *et al.* 2003). High concentrations of acidifying agents in the atmosphere originated mainly from thermal power stations both in the Czech Republic and in Poland. Mean annual deposition rates of SO_3^- reached several tens or even hundreds of g/m^2 during the 1970s and 1980s (Czech Hydrometeorological Institute 2010). Though the acid emissions have decreased significantly in recent years, the ecosystem still remains threatened by acidifying agents accumulated in soil (Oulehle *et al.* 2006; Borůvka *et al.* 2007; Hédl *et al.* 2011). The most affected were forest stands at the highest elevations (Purdon *et al.* 2004). A timescale under which soils can develop must be taken into consideration. The podzolization process can be considered as rather fast. Significant morphologic changes of the soil profile can be observed within a relatively short period. Significant changes in the soil chemistry and morphology that indicate the podzolization process can be observed already after a few tens or hundreds of years (Olsson & Melkerud 1989; Mokma *et al.* 2003; Zanelli *et al.* 2007; Dlouhá *et al.* 2009; Kalinina *et al.* 2009).

Study area

The study area is situated in the southern part of the Krkonoše National Park (Figure 1), part of the Sudetes Mts. in the north of the Czech Republic. The wider area has a mountainous character with

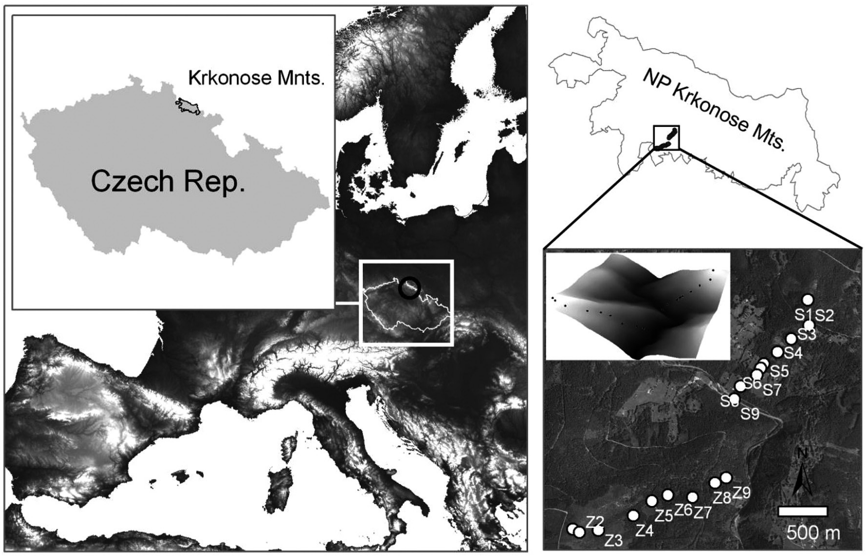

Figure 1. Geographic location of the Krkonoše Mts. and transects within the studied area

high relief intensity. The central part is traversed by the Elbe River, forming a deeply incised valley with adjacent slopes reaching up to 45°. The altitude varies from 565 m at the Elbe floodplain to 1036 m above sea level (Zadní Žalý Mountain). A pronounced influence of climatic altitudinal zones, manifested by an increase in annual precipitation and a decrease in mean temperature with increasing altitude, is characteristic of the area. Average annual temperature rises from 4–5°C at the upper parts of the studied area to 6–7°C in the valley of the Elbe River. Temperature difference is more significant in summer than in winter (Halásová *et al.* 2007). Annual precipitation varies between 1000 and 1400 mm/year (less in the valley, more at the summits). The spatial distribution can significantly differ locally due to air circulation (Halásová *et al.* 2007) but more detailed data are not available. Permanent snow cover varies between 50 and 250 cm (average 80 cm) and remains up to 7 months at higher elevations. The snow cover is preserved in forested areas in the spring season for a longer time than on the open areas (Pobříslová & Kulasová 2000).

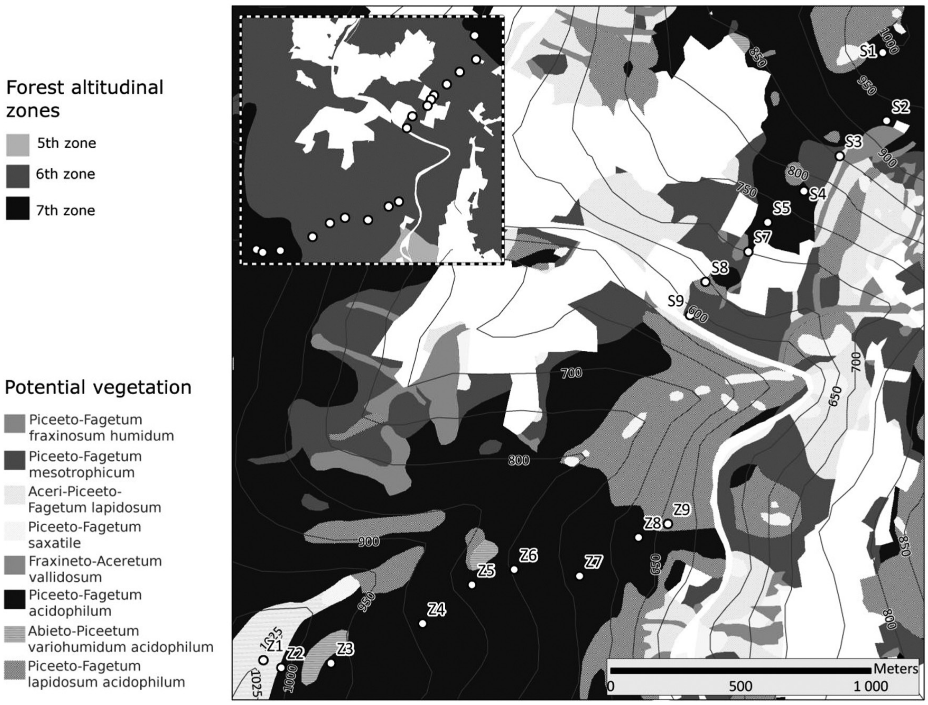

Figure 2. Forest altitudinal zones and potential forest types in the wider studied area

The Krkonoše Mts. belong to the West-Sudetes geomorphological and geological subprovience (Chlupáč 2002). The area of the two studied transects is built of biotite-muscovite gneiss (Czech Geological Survey 2012). The area is composed mainly of Proterozoic metamorphites, namely gneiss and micaceous schist. Haplic Podzol, Entic Podzol and Dystric Cambisol are the most extensive soil units in the area.

According to the Czech forest ecosystem classification, the area comprises two forest altitudinal zones 6^{th} – 7^{th} (for details see Viewegh *et al.* 2003). Potential vegetation is characterized by: *Fageto-Piceetum oligotrophicum*, *Fageto-Piceetum acidophilum*, *Piceeto-Fagetum acidophilum*, *Piceeto-Fagetum lapidosum acidophilum* and *Piceeto-Fagetum mesotrophicum* (Figure 2). According to the Map of Potential Natural Vegetation of the Czech Republic (Neuhäuslová & Moravec 1997), the studied area belongs to spruce-beech forest (*Calamagrostio villosae-Fagetum*), at lower altitudes partially to beech forest (*Dentario enneaphylli-Fagetum*). Chuman and Romportl (2010) classify the given area as moderately cold to moderately warm uplands and hills.

In reality, the spruce monoculture of different age covers the whole studied area. Broadleaf trees (birch, beech) are present locally. The replacement of natural broadleaf forest or mixed forest by spruce monocultures started in the 18^{th} century and drastically changed the original forest structure of the Krkonoše Mts. (Figure 3; Vacek *et al.* 2008).

A detailed research was carried out in two terrain transects (Figure 1). Transect Z is located at the summit of Zadní Žalý Mountain (1036 m) down towards the Elbe alluvium. Transect S was realized at the opposite side of the valley, starting at the summit of Struhadla Mountain (1002 m). Observation sites were chosen to represent the common local conditions at the sampled location and to avoid sampling in places affected by tree falls that can significantly influence soil development (Šamonil *et al.* 2010). The final choice of soil pits at each location was done after quick examination of the local area by four to five shallow digs.

MATERIAL AND METHODS

Nine observation points were chosen in each of the two transects. Each of the sampling points represents approximately 50 elevation meters. The aim of such scheme was to cover the entire altitudinal range of the area. The points were

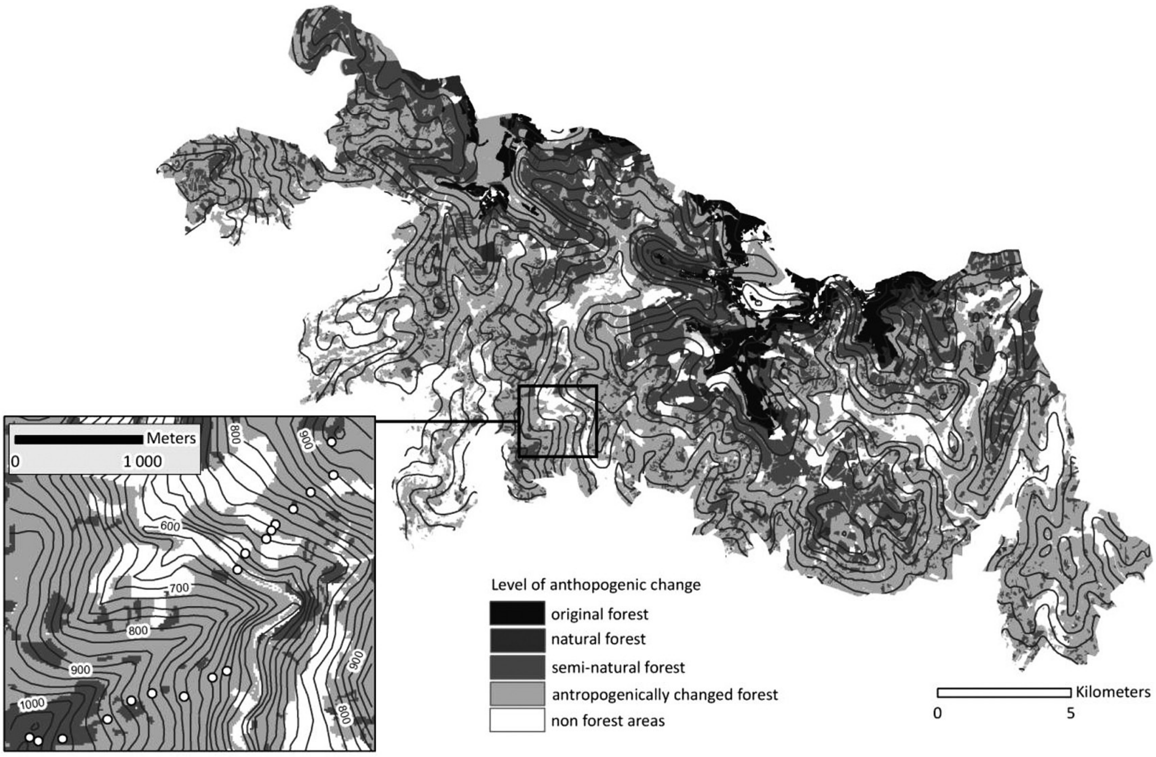

Figure 3. The level of anthropogenic influence on forest types in the Krkonoše Mts. National Park and studied area

located in very similar vegetation and geological units. This method guarantees the elimination of other soil-forming factors except for the altitudinal influence. Sampling points were localized by GPS device.

The soil survey was focused on the morphological description of soil profiles and classification of soils according to the present diagnostic horizons. A simplified version of the World Reference Base for Soil Resources (WRB), version 2006 (FAO 2006) was used for the soil classification. The soil unit was determined in each pit and samples were analysed for selected morphological features in the field: soil depth, soil profile stratigraphy, horizon depth, soil colour (according to Munsell colour charts) and diagnostic properties if present. Samples from each diagnosed subsurface horizon were taken for laboratory analyses (pH_{H_2O}, pH_{KCl}, cation exchange capacity and base saturation). Soil colour, pH and iron coatings (observed by a binocular; 200× magnified) were taken as diagnostic criteria for the spodic horizon recognition; soil colour and thickness are diagnostic criteria for albic horizon (WRB; FAO 2006).

RESULTS

Morphological properties

Five soil subtypes were found in the study area (Figure 4). Haplic Podzol was the prevailing soil unit, complemented with Entic Podzol, Dystric Cambisol, Haplic Leptosol and Stagnic Cambisol. The presence of Haplic Leptosol was conditioned by the extreme terrain position. Stagnic Cambisol was found in a local spring area. Vegetation cover was described together with the soil units. Spruce

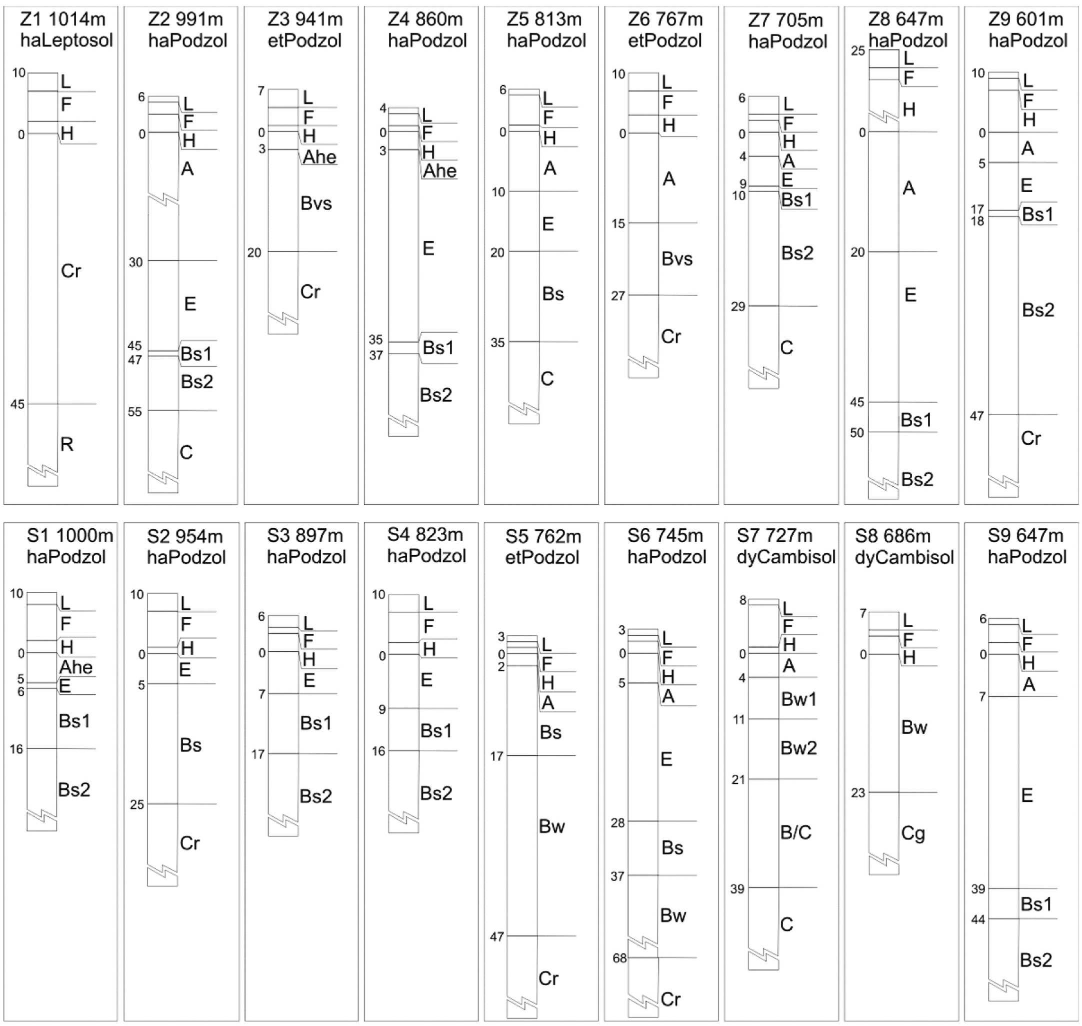

Figure 4. Soil profiles of the two transects; the depth of soil horizons is given in cm

was the prevailing and (at most places) the only tree species. In some locations accessory tree species were present, but only as individual stands. The forest floor varied in herbal species. Spruce litter was the only cover at some locations (Table 1).

All the soil profiles are characterized by the presence of a significant layer of spruce litter in Mor form (O, further subdivided into L, F, H) with average thickness of 8.3 cm. Surface horizons (A) are rather shallow (average 8.3 cm) or are not present. In general, the soils are shallow or medium deep, rarely exceeding the depth of 50 cm.

Haplic Podzols are characterized by a sequence of horizons: O-A-E-Bs1-Bs2-Cr. The albic eluvial horizon (E) is usually well developed, characterized by light colour with high value (5–6) and low chrome (2–3). Two spodic horizons are typically present in the profile: Bs1 – which is characterized by darker colour (most often 7.5 YR 4/6) caused by the presence of humus substances and Bs2 – which is lighter in colour with higher chrome (most often 7.5 YR 4/4) given by presence of high amount of the iron. The Bs1 horizon is usually shallow (average 5.0 cm) or in some cases it is present only partially or is missing at all. The Bs2 horizon is always well developed (average depth 18.9 cm) and fulfils the morphological criteria for a spodic horizon including the presence of iron coatings (FAO 2006). The parent material is characterized by a high amount of skeleton content.

The Entic Podzols are characterized by the following sequence of horizons: O-A-Bs-(Bw)-Cr. The albic horizon is missing due to the lower intensity of podzolization. The lower parts of humus horizon (A) show some features of iron leaching characterized by sand and silt grains free of coating.

Table 1. Vegetation cover at observed soil pits (potential and observed during survey)

Profile	Soil unit	Potential vegetation (forest site complex)	Observed vegetation		
			dominant	accessory	plant (herb) species
Z1	haLP	*Fageto-Piceetum humilis*(*-e*)	spruce	–	*Calamagrostis villosa*, *Deschampsia cespitosa*
Z2	haPZ	*Fageto-Piceetum oligotrophicum*	spruce	–	*Calamagrostis villosa*, *Vaccinium vitis*
Z3	etPZ	*Fageto-Piceetum acidophilum*	spruce	–	*Nardus stricta*
Z4	haPZ	*Piceeto-Fagetum acidophilum*	spruce	–	*Dryopteris filix-mas*
Z5	haPZ	*Piceeto-Fagetum acidophilum*	spruce	beech	*Vaccinium myrtillus*
Z6	etPZ	*Piceeto-Fagetum acidophilum*	spruce	beech	*Dryopteris filix-mas*
Z7	haPZ	*Piceeto-Fagetum acidophilum*	spruce	sorbus	*Vaccinium myrtillus*, *Nardus stricta*
Z8	haPZ	*Piceeto-Fagetum lapidosum acidophilum*	spruce	–	no (only spruce litter)
Z9	haPZ	*Piceeto-Fagetum lapidosum acidophilum*	spruce	–	no (only spruce litter)
S1	haPZ	*Fageto-Piceetum acidophilum*	spruce	–	*Calamagrostis villosa*
S2	haPZ	*Piceeto-Fagetum acidophilum*	spruce	–	*Calamagrostis villosa*, *Vaccinium myrtillus*
S3	haPZ	*Piceeto-Fagetum acidophilum*	spruce	–	*Vaccinium myrtillus*
S4	haPZ	*Piceeto-Fagetum mesotrophicum*	spruce	sorbus	no (only spruce litter)
S5	etPZ	*Piceeto-Fagetum acidophilum*	spruce	sorbus	*Nardus stricta*, *Vaccinium myrtillus*
S6	haPZ	*Piceeto-Fagetum acidophilum*	spruce	–	*Vaccinium myrtillus*, *Dryopteris filix-mas*
S7	dyCM	*Piceeto-Fagetum acidophilum*	spruce	beech	*Blechnum spirant*, *Dryopteris filix-mas*
S8	dyCM	*Piceeto-Fagetum mesotrophicum*	spruce	–	*Blechnum spirant*
S9	haPZ	*Piceeto-Fagetum lapidosum acidophilum*	spruce	–	no (only spruce litter)

Cambisols consist of the typical horizon sequence: O-A-Bw-Cr. The cambic horizon is characterized by intensive weathering of the parent material that is morphologically significant by colour change. Sand and silt coating-free grains can be found in some parts of the profile.

Chemical properties

In general, all the studied soils are strongly acid (Table 2). The distribution of the values varies within the soil profiles (Figure 5). The lowest pH was determined in A-horizons. Haplic Podzols have very low pH in the eluviation horizon (E) that significantly differentiates these soils from the other soil types. Values within the spodic horizons are similar for Haplic Podzols and Entic Podzols. Significantly higher pH is found in the cambic horizon. Differences in pH decrease towards the lower part of the soil profile. The horizons of the parent material, which correspond most to the original rock, have the highest pH. The difference in pH is the most significant in Haplic Podzol; no change of pH was found between Bw and C horizons of Dystric Cambisol. This reflects the intensity of acidification from external sources.

The cation exchange capacity (CEC) was measured only in the inner horizons. Significant differences were determined in the CEC stratification within the soil profiles of Cambisols and Podzols. In Podzols, CEC increases with depth; this is given by the presence of spodic horizon with precipitated organic acids and sesquioxides (Figure 5). In Cambisol, the CEC is higher in cambic horizon where development of clay particles is a part of braunification process and CEC decreases in the parent material horizon.

Base saturation of all horizons is very low. The lowest values feature the eluvial and cambic horizons. Both these horizons underlay directly the surface humus horizon. This causes a strong acidification process. The highest base saturation values were determined in spodic horizon and parent material.

Chemical properties of Haplic Podzols that describe the intensity of podzolization process were examined in more detail. The relationships between soil reaction, thickness of eluvial horizon (E), thickness of litter layer (O) and altitude were studied using linear regression. None of these properties showed a significant dependence on the altitude (Figure 6). A trend of the increasing thickness of litter layer (O horizon) with altitude can be observed. This can be explained by less favourable conditions of organic matter decomposition at higher altitudes given by colder climatic conditions. The relationship between the thickness of E horizon and litter O is also obvious, but not statistically proved again (Figure 6b).

Table 2. The overview of observed and measured properties within horizons for all soils

Horizont	Cnt	Most frequent colour (moist)	Horizont thickness		pH_{H_2O}		pH_{KCl}		CEC		BS (%)	
			cnt	mean (SD)	cnt	mean (SD)	cnt	mean (SD)	cnt	mean (SD)	cnt	mean (SD)
L	–	–	18	1.9 (0.9)	–	–	–	–	–	–	–	–
F	–	–	18	3.2 (2.1)	–	–	–	–	–	–	–	–
H	–	–	18	3.2 (4.4)	–	–	–	–	–	–	–	–
A	13	10YR3/2	13	8.7 (8.3)	–	–	2	2.7 (0.2)	–	–	–	–
E	12	10YR5/2	12	14.3 (10.5)	10	3.5 (0.2)	10	2.9 (0.3)	10	22.1 (13.2)	9	20.2 (6.6)
Bs1	10	7.5YR4/6	10	5.0 (3.9)	6	3.7 (0.4)	5	3.4 (0.5)	5	22.0 (3.2)	5	21.5 (7.1)
Bs2	7	7.5YR4/4	7	18.9 (9.6)	12	4.0 (0.2)	12	3.7 (0.3)	12	22.5 (7.6)	12	27.2 (8.1)
Bvs	2	10YR4/5	2	14.5 (3.5)	2	4.0 (0.3)	2	3.7 (0.3)	2	18.8 (1.4)	2	26.6 (4.3)
Bw	4	10YR4/6	4	17.5 (10.8)	3	3.8 (0.3)	3	3.4 (0.4)	3	20.0 (4.6)	3	18.2 (11.1)
C	20	10YR4/4	20	–	9	4.1 (0.3)	9	3.8 (0.5)	9	15.0 (3.2)	9	26.8 (7.9)
Total	68	–	122	12.8 (10.5)	43	3.9 (0.3)	44	3.4 (0.5)	42	20.3 (8.2)	41	23.9 (8.1)

Cnt – count; SD – standard deviation; CEC – cation exchange capacity; BS – base saturation

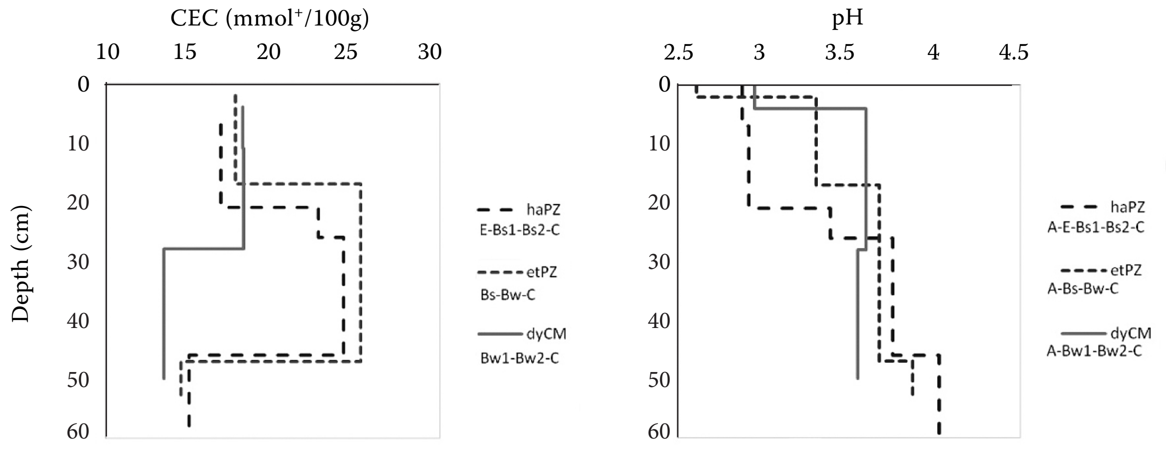

Figure 5. The distribution of the soil reaction and cation exchange capacity values in mineral horizons through the profile for particular soil units

The litter layer as a source of acid humus material is responsible for the intensity of podzolization process that is described in this case as thickness of E horizon. Similar results were found by Titeux *et al.* (2002). In general, the pH of the E horizon is extremely low. The soil reaction of eluvial horizon does not change with the altitude (Figure 6a).

Distribution of soil units

Distribution of soil units within transects is not regular (Figure 7). The common hypothesis, which considers the sequence of Dystric Cambisol, Entic Podzol, Haplic Podzol with increased altitude, was not proved. The presence of Cambisols and

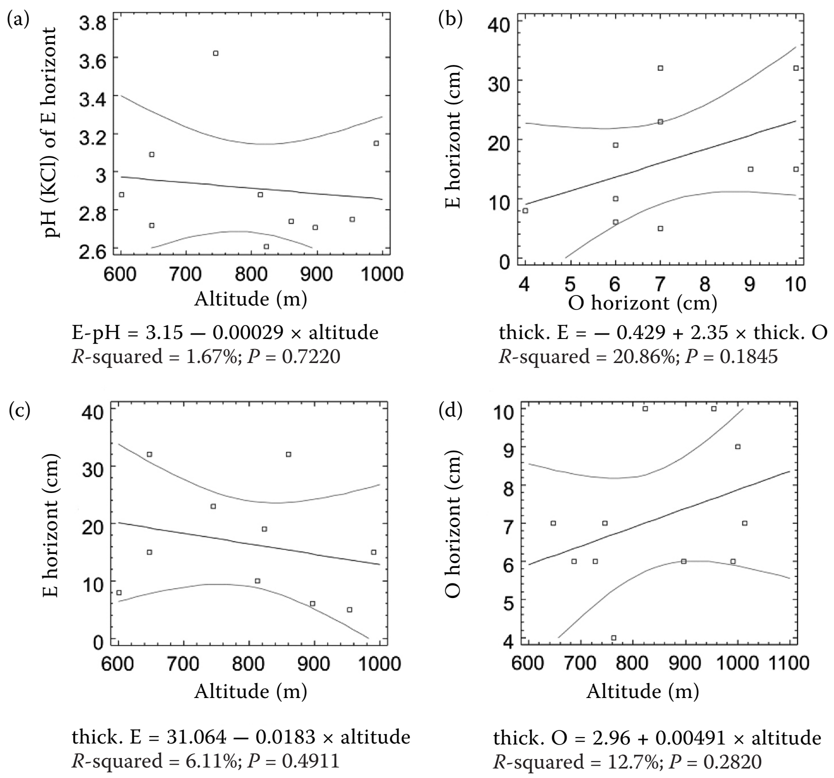

Figure 6. Linear regression with confidence intervals (P = 0.05) of: (a) altitude and pH of E horizon (upper left), (b) thickness of litter O and E horizon (upper right), (c) altitude and thickness of E horizon (lower left), (d) altitude and thickness of litter O (lower right)

Entic Podzols follows this trend, but no relation was found between altitude and the presence of Haplic Podzols (Figure 7). Cambisols are present at lower altitudes of the research area while Entic Podzols occur at higher altitudes of the studied transects. Haplic Podzols were found at all elevation zones ranging from the lowest part (601 m) of the studied area to the highest (1000 m).

DISCUSSION

Chemical properties

Strong acidity, found in all horizons, corresponds to studies describing similar environmental conditions. Borůvka *et al.* (2005) found the same trends of soil reaction in soil profiles in forests of the Jizerské hory Mts. (part of the Western Sudetes Mts.). Very low pH and a slight increase with depth, as found in our study, were observed by Drábek *et al.* (2007), Egger and Hewitt (2008) or Dlouhá *et al.* (2009). The observed different trend of pH values within the profile in different soil units corresponds to results obtained by Emmer *et al.* (1997), who also reported the most significant change in Haplic Podzol and no change in pH between Bw and C horizon in Dystric Cambisol.

The acidification can be explained by vegetation cover, especially by spruce litter that causes a decrease in pH by releasing humic acids (Vavříček & Šimková 2000). This influence decreases with depth. pH is higher in lower horizons where the

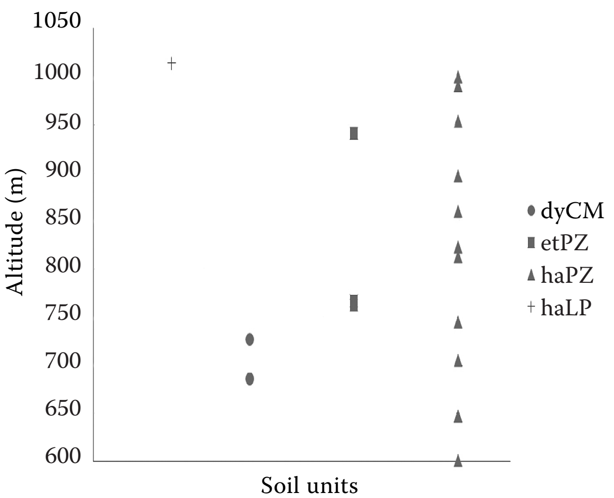

Figure 7. The distribution of soil units at the studied altitudinal profiles

influence of the parent material is higher. The anthropogenic acidification, which is represented by sulphur and nitrogen deposition, can be another factor increasing the acidity in the upper part of the soil profile (Mládková *et al.* 2005; de Schrijver *et al.* 2006).

The higher sensitivity of surface horizons to external impacts such as acid deposition, liming, or forest management is obvious from Figure 5. Different soil units show significantly different trends of pH as a result of their soil formation caused by the influence of external soil-forming factors and their intensity. Deeper mineral horizons are influenced to a greater extent by autogenic soil-forming processes (weathering) and parent material chemistry.

No direct relationship was found between the intensity of podzolization process and altitude (Figures 6a, b). Borůvka *et al.* (2005) explained this fact by the influence of vegetation cover. Spruce forest as a big pool of exchangeable H^+ shows lower pH values at lower altitudes while beech forest at higher altitudes has higher pH. Our study did not prove the trend of pH decrease with increasing altitude in the transect with uniform vegetation as was reported by Griffiths *et al.* (2009). This can be explained by the intensive influence of uniform vegetation (spruce) that overrules the other soil-forming factors as temperature change or duration of snow cover within the 450-m altitude range of the studied area.

Base saturation provides similar trends as soil reaction. All the horizons are strongly unsaturated and the base saturation increases in deeper mineral horizons (toward C). Obtained values and trend correspond to results of Álvarez Arteaga *et al.* (2008), who found low base saturation (BS) in all the soils of the studied toposequence. Emmer *et al.* (1997) found lower BS (24%) in spruce forest and higher BS (34%) in beech forest 34%. Obviously, the BS is strongly influenced by the vegetation cover as well.

The distribution of the cation exchange capacity differs significantly within the soil units. High values in spodic horizons (both Bhs and Bs) and significant decrease in the parent material are typical of both Haplic and Entic Podzols. The average value of CEC in the eluvial horizon is quite high. The highest values were found in two shallow eluvial horizons (S3, S4) that are rather less developed. Higher CEC can be explained by the presence of humic substances in the eluvial horizon, because eluvial horizons with the albic properties (e.g. S9) have significantly lower CEC values.

Distribution of soil units

Distribution of soil units within the studied transects does not correspond to results of other authors that studied the altitudinal sequence of soils (Němeček & Tomášek 1983; Lundström *et al.* 2000a; Bonifacio *et al.* 2006; Seibert *et al.* 2007; Egli *et al.* 2008). The common hypothesis that considers the sequence of Dystric Cambisol-Entic Podzol-Haplic Podzol with increased altitude was not fully proved. Haplic Podzols occur in a wide range of altitudes starting at the low altitude (600 m) that is rather typical of Dystric Cambisols and Entic Podzols.

We used two studies for a comparison of our results that provide enough reference data from the wider area of the Western Sudetes Mts. (Figure 8). Podrázský *et al.* (2006) studied the soil development at monitoring sites with original natural vegetation (750–1300 m). They found the typical altitudinal toposequence of Dystric Cambisols-Entic Podzols-Haplic Podzols. Dystric Cambisols and Entic Podzols were bound to the beech forest type while Haplic Podzols were found only under spruce forest. All the soil units reach high elevations (up to 1200 m). It is obvious from Figure 8 that there is an overlapping altitudinal zone where different soil units are defined by different vegetation type. Another study (Pavlů *et al.* 2007) showed a similar trend but at lower altitudes (700–1000 m). Dystric Cambisols and Entic Podzols were found at a low elevation where beech forest was present and at a wide range of altitudes with spruce forest. This wide range of altitudes where Haplic Podzol can be found fully corresponds with our study. The fact that Haplic Podzols can be found at quite a low elevation was proved in the study of Dlouhá *et al.* (2009), who also found fully developed Haplic Podzol at 700 m in the close proximity of our study area.

The results of our study and two compared studies indicate that the influence of spruce vegetation causes the occurrence of Haplic Podzols at low altitudes where original natural soil-forming factors were not favouring the Haplic Podzol development. Obtained results show that the vegetation type can overrule other forming factors given by altitude (such as temperature or precipitation gradient) that are responsible for soil development. The same conclusion was drawn by Berger *et al.* (2002), Porębska *et al.* (2008) or Borůvka *et al.* (2009). A typical altitudinal soil toposequence is found only where the original natural vegetation is present and where its distribution is driven by

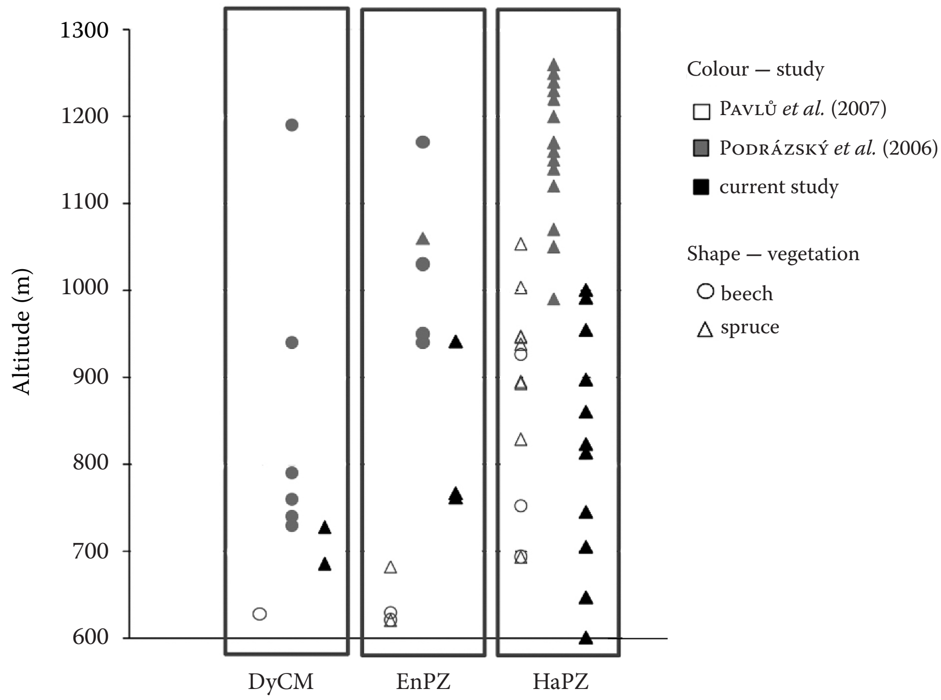

Figure 8. Distribution of soil units within the altitudinal transect. Comparison of obtained results with the study of Podrázský *et al.* (2006) and Pavlů *et al.* (2007)

the altitudinal zonation. The soil toposequence formation is promoted by the synergy effect of soil-forming factors such as climatic changes with altitude in the natural vegetation cover.

When we consider the timescale of spruce plantation in the area, it has been long enough for Podzol development (Mokma *et al.* 2003; Zanelli *et al.* 2007; Kalinina *et al.* 2009). The timescale, which is represented by two centuries of spruce monoculture planting (Vacek *et al.* 2008), provided enough time for the full development of Haplic Podzols. The change in forest type by spruce planting altered the soil cover pattern mainly at lower altitudes, where the forest management consisting in spruce monoculture planting replaced the original broadleaf natural vegetation. The original beech forests were fully converted to a new type of forest, while mixed forests at middle altitudes or natural spruce monocultures at high altitudes were less influenced.

Anthropogenic acid deposition, which has intensively occurred for decades, very probably plays a certain role in the enhancement of podzolization process in the area as an important factor in chemical changes connected with podzolization (Olsson & Melkerud 1989; Lundström *et al.* 2000a; Borůvka *et al.* 2007). The soils have a very low buffering capacity, so a further increase of acidification can start the podzolization process. Its intensity in relation to Haplic Podzol development is not fully explained in this study.

CONCLUSIONS

Our study shows how changes in environment properties, which represent soil-forming factors, can influence the pattern of soil cover. The study focuses on changes in the long run that are represented by morphological features characteristic of each soil unit. The distribution of soil units (Dystric Cambisol-Entic Podzol-Haplic Podzol) within the studied altitudinal transects does not correspond to results of other authors that studied the altitudinal sequence of soils under natural vegetation. The conversion of natural broadleaf and mixed forests to spruce monocultures in combination with anthropogenic acid depositions changed significantly the soil-forming conditions. This led to the expansion of podzolization process to lower altitudes. These changes resulted in a significant enlargement of the Haplic Podzol area from former high-altitude stands in natural spruce forests to lower altitudes with spruce monocultures. Even, the effect of stand factors is complex; the influence of vegetation is a major soil-forming factor ruling the soil cover development in this case. The present soil cover in the Krkonoše Mts. is a result of both natural and human-induced factors.

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