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Transformation of physicochemical soil properties along a mountain slope due to land management and climate changes — A case study from the Karkonosze Mountains, SW Poland

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ABSTRACT

The gradients of soil physicochemical properties along mountain slopes and across climate-elevation gradients were studied in the Karkonosze Mountains, focusing on the human-impacted zonality of the vegetation cover. The main focus of the study was the environmental consequences, both human-induced and spontaneous, of vegetation changes in the mountains which may occur due to climate change. In soils developed from granite, a clear altitude-related differentiation of soil properties was manifested by: (i) an increase in total organic carbon (TOC) with elevation; (ii) an increase in exchangeable acidity and aluminum (Al_{ex}); (iii) a decrease in pH, (iv) a decrease in base saturation; and (v) finer soil texture and higher content of base cations in the foothills and lower slopes. These altitude-dependent trends have a threshold-type distribution, i.e. the values stabilize at 750–1000 m a.s.l. or are reversed in the subalpine zone. Grass vegetation decreased TOC and Al_{ex}, but increased soil pH and base saturation compared with forest vegetation at the same altitude zone. Soils under spruce had higher TOC but lower pH compared with beech stands.

Present-day changes of mountain area management in Central Europe, i.e. the replacement of spruce monocultures with beech or mixed stands in the lower forest zone and reforestation (mainly with spruce or mountain pine) of abandoned meadows and pastures at and above the timberline significantly influence topsoil properties, but there is a contrasting direction of changes in the lower and upper altitude zones. Expected climate changes may shift the upper limits of the individual forest zones and reinforce the ongoing changes in forest management. The final regional result of changes is difficult to calculate and strongly dependent on the degree of anthropogenic transformation of vegetation cover. However, both the current changes in management practices and possible climate changes will reinforce the existing vertical gradients of mountain soil properties, including the elevation-related increase in TOC, exchangeable acidity and Al_{ex}, as well as the decrease in soil pH and base saturation.

1. Introduction

The diversity of the soil physicochemical properties in mountain areas depends on a variety of natural and anthropogenic factors. Among the natural factors, the most important are the parent rock, topography, and vegetation cover. Also, altitude plays a crucial role in mountain landscapes, where the elevation gradient may affect the microclimate, circulation of air masses, and vegetation cover over a small area (Sobik et al., 2013). Climatic factors, especially air temperature, annual precipitation, and water balance determine the direction and intensity of physical, chemical and biological processes, including weathering, in soil and on its surface (Jenny, 1994; Lesovaya et al., 2012; Rubinić et al., 2015; Schawe et al., 2007). Furthermore, slope position and microrelief are important, although on a more local scale (Migoń and Kacprzak, 2014; Szewczyk et al., 2015; Tsui et al., 2004; Waroszewski et al., 2015; Yimer et al., 2006). Also, climate may affect the soil properties indirectly by its influence on the vegetation cover (Fu et al., 2004). Elevation increase is accompanied by climate–vegetation zones differing in dominant species and the vertical structure of the plant communities (Álvarez Arteaga et al., 2008; Neuhäusl and Neuhäuslová, 1994). The vegetation type affects the amount and type of soil organic matter (Bojko and Kabala, 2014; Labaz et al., 2014; Leifeld et al., 2005; Li et al., 2010; Martin et al., 2010), biological activity (Drewnik, 2006; Gutiérrez-Girón et al., 2015; Puissant et al., 2015; Smith et al., 2002), topsoil physical properties (Rezaei and Gilkes, 2005a), the soil pH and the degree of leaching or accumulation of base cations (Galka et al., 2014b; Gruba, 2009; Rezaei and Gilkes, 2005b), accumulation of macro- and microelements, including trace metals (Glina and Bogacz, 2013; Szopka et al., 2010, 2013), and the intensity of pedogenesis in general (Pastalkova et al., 2001). Some anthropogenic factors may have a direct effect on the properties of mountain soils; these

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factors are connected with mining, agriculture, tourism, and industrial emissions (Novák et al., 2014; Szopka et al., 2011). However, the indirect impacts are more commonly connected with human-induced changes in vegetation, as in the case of the conversion of forests into pasture and arable land, or changes in the dominant forest species, e.g. from deciduous to coniferous ones (Bolliger et al., 2008; Galka et al., 2014a; Jandl et al., 2007; Jäger et al., 2015; Wasak and Drewnik, 2015).

Sensitive mountain ecosystems are the most vulnerable, and thus quickly respond to climate changes (Degórski, 2005; Hagedorn et al., 2010). The development or transformation of soils is most evident in mountain areas with disappearing glaciers (Bockheim, 2015; Egli et al., 2006; Kabala and Zapart, 2012; Migała et al., 2014). On a global scale, many soil scientists have recognized various effects of climate change on soil organic matter (Lal, 2014). Less attention has been paid to changes in the weathering rate or physicochemical properties that may undergo due to a shortening of the snow cover period or an extension of the summer desiccation of mountain soils (Goldberg et al., 2010; Smith et al., 2002).

The Karkonosze Mountains, the highest range of the Sudeten, are characterized by the zonation of microclimate conditions and vegetation cover, typical of a temperate climate. This zonation and the relatively homogeneous parent rock in the northern slopes allow the environmental results of climate changes or human activity to be tracked. Soils of the Karkonosze Mountains are relatively well investigated — in terms of spatial diversity (Kabala et al., 2013a,b; Waroszewski et al., 2016), origin of the soil cover (Kabala et al., 2010; Waroszewski et al., 2010, 2013), and the causes, history and degree of contamination (Glina and Bogacz, 2013; Kabala and Bojko, 2014; Kabala and Szerszen, 2002; Malkiewicz et al., 2016; Szopka et al., 2011, 2013; Waroszewski et al., 2009). However, so far no model has been proposed to describe the basic physical and chemical properties of soils across the entire climate-elevation slope gradient and across different types of vegetation. Meanwhile, such a model should provide the necessary basis for a geoecological analysis, including the effects of climate change and for environmental management, including active nature conservation, i.e. reconstruction of semi-natural forests, species restitution, and reforestation (Brevik et al., 2016).

The aim of this study was to characterize the gradients of the physicochemical soil properties along the mountain slope (including soil profile morphology) and the climate-elevation gradient, focusing on vegetation zonation and the human-impacted structure of the vegetation cover. The general aim was to determine how strongly the type of land use and the species composition of mountain plant associations related to the climate or to human activity can influence the soil properties. This may answer questions about the environmental consequences, both human-induced and spontaneous, of vegetation changes in the mountains, which could occur due to climate change.

2. Materials and methods

2.1. Area of study

The study was conducted in the Karkonosze Mountains, situated in south-western Poland, close to the border with the Czech Republic (Fig. 1). The Karkonosze Mountains are the highest range of the Sudeten (the highest peak — Mount Śnieżka, 1602 m a.s.l.). The main part of the Karkonosze Mountains is developed from Carboniferous granites, upraised mainly during the Variscan orogeny. The granite massif is surrounded by Paleozoic metamorphic rocks, including gneisses, schists, dolomites, and greenstones (Aleksandrowski et al., 2013). All soil profiles were located in the granite part of the Karkonosze Mountains.

The Karkonosze Mountains are influenced by a suboceanic climate, with significant influences of continental air masses (Gramsz et al., 2010). Despite their relatively small area, there is a wide variation of climatic conditions in the Karkonosze Mountains resulting from morphological factors (e.g. an orographic barrier) and seasonal circulation of air masses. However, the most important factor is the vertical diversity of climatic conditions related to altitude gradient. The mean annual air temperature decreases from 7.9 °C in the foothills to 0.4 °C on Mt. Śnieżka (Table 1). The decrease in temperature with elevation is very clear: on average 0.59 °C per 100 m of altitude. The mean annual precipitation increases from 700 to 750 mm in the foothills to approx. 1500 mm in the highest parts. The duration of the snow cover period varies from 60 to 65 days in the foothills, 130–140 days at 900 m a.s.l., and up to 180–200 days in the upper forest zone. The Karkonosze Mountains are one of the windiest mountains in Europe (in terms of the frequency and speed of winds), dominated by south and southwest winds (Kwiatkowski and Holdys, 1985; Sobik et al., 2013).

Five natural climate-induced vertical vegetation zones, typical for mid- and high-mountains of the Central Europe, are recognizable in the Karkonosze Mountains; however, land and forest management have strongly influenced the species composition. Natural broadleaf forests in the submountain zone (<500 m a.s.l.), presumably *Galio–Carpinetum* and *Luzulo–Quercetum* communities, are preserved fragmentarily due to common agricultural land use at this altitude or forest conversion to spruce stands (Danielewicz et al., 2013). The lower mountain forest zone (500–1000 m a.s.l.), potentially a habitat for *Luzulo–Fagetum* and *Abieti–Piceetum* communities, is mainly covered by human-introduced mono-species Norway spruce stands. The upper mountain forest zone (1000–1250 m a.s.l.) is, due to its climate, naturally dominated by a *Calamagrostio villosae–Piceetum* community with Norway spruce as the prevailing tree species. The subalpine zone (1250–1450 m a.s.l.) is a mosaic of phytocenoses with shrubs of mountain pine (*Pinetum mugo sudeticum*) and mat grass-meadows (*Carici-Nardetum*), with several unique communities on the bogs and in the glacial cirques. The alpine zone (1450–1603 m a.s.l.) in the Karkonosze Mountains covers only small areas around the highest peaks and is represented by herbaceous communities such as "sparse meadows" with mountain rush (*Carici–Festucetum airoidis*). The transformation of natural vegetation in the Karkonosze Mountains proceeded in two ways: (1) in the upper mountain zones — the native spruce forests and mountain pine shrubs were cut, and transformed into pasture; and (2) in the lower forest zone the native beech and beech–fir stands were replaced by fast-growing spruce (Danielewicz et al., 2013). As a result of so-called ecological disaster, thousands of hectares of spruce stands in the Sudeten Mountains were damaged in the 1970–1980s. This fact shows the natural and economic necessity of remodeling forest structure. Reconstruction of spruce monocultures towards mixed or deciduous stands, in accordance with the environmental conditions of a habitat, is now postulated in all mountain forests, especially in protected areas (Galka et al., 2013,b).

The soil cover structure of the Karkonosze Mountains relates largely to the vegetation and altitude zones (Fig. 2). Haplic/Stagnic Luvisols dominate in the foothills (below 500 m a.s.l.). Dystric Cambisols, often podzolized, mostly occur in the upper foothills and the lower forest zone, in the range of 500–800 m a.s.l. The 800–1000 m a.s.l. zone is dominated by Albic Podzols (with skeleton content increasing with altitude). In the upper forest zone and in the subalpine zone, the main soil types are Stagnic/Histic Podzols and Histosols. The peaks above 1400 m a.s.l. are almost covered with Lithic/Hyperskeletic Leptosols. The borders between soil zones are not sharply defined and depend on the local slope morphology, periglacial cover beds, water regime, and present-day activity of geomorphological processes, including erosion, mass movement, and wind-throw effects (Kabala et al., 2013a,b; Šamonil et al., 2015; Traczyk and Migoń, 2003).

2.2. Field and laboratory methods

Litter and soil samples were collected at 52 sites located in five altitude zones: 400–500, 500–750, 750–1000, 1000–1250, and 1250–1450 m a.s.l., and under different vegetations, including cereals (in arable lands), grasses (on meadows, pastures, and ski trails), European beech (*Fagus sylvatica* L.) stands, Norway spruce (*Picea abies* (L.)