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Organic carbon pools in mountain soils — Sources of variability and predicted changes in relation to climate and land use changes

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ABSTRACT

The overall impact of individual environmental factors on the content of soil organic carbon (SOC) is well known, but the simultaneous impacts of natural and anthropogenic factors on the amount and diversity of SOC pools in mountain areas are still insufficiently recognized. This study has three objectives: (1) to determine SOC pools in the mountain toposequence in relation to the climate-elevation gradient and vertical vegetation zonality, largely as a result of interference caused by human activity; (2) to predict the fluctuations of SOC pools in mountain soils affected by changes in land use/forest management and expected climate warming; and (3) to verify whether the humus form is a predictor of SOC pools in mountain soil. A spatial, climate-/altitude-dependent trend of SOC pools is clearly marked on the northern slopes of the Karkonosze Mountains, SW Poland. These SOC pools gradually increase up to the altitude of ca. 1000 m a.s.l. and then decrease in the uppermost forest and subalpine zones. The SOC pools are also strongly related to land use/vegetation (arable soils < grasslands = European beech stands < Norway spruce stands) and soil type (Luvisols < Cambisols < Podzols). Humus forms reflect the differences in SOC pools (mull < moder < mor), but the recent European classification does not clearly allocate semiterrestrial sub-types among mor and moder humus forms. Expected climate warming and present changes in land use and forest management lead to similar changes in SOC pools. However, replacing spruce monocultures with mixed or broadleaf stands reduces the SOC pools in the lower forest zones, while the timberline rise and the succession of Norway spruce on grasslands increases SOC pools in the upper forest and subalpine zones. Thus, the balance of SOC pools caused by changes in land use and climate warming will be specific in particular mountain areas, depending on their maximum altitude and existing vegetation zones, the degree of anthropogenic transformation of ecosystems, and the resilience of ecosystems to climate changes. It is expected that the SOC pools in the Karkonosze Mts and similar medium-elevation mountain ranges of Central Europe will decrease due to the larger scale of phenomena which decrease SOC pools.

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1. Introduction

Soil organic matter fulfills several functions such as: impact on soil structure and porosity, regulation of cation sorption and water retention, regulation of the solubility, mobility and availability of macro- and micro-elements, carbon source for microorganisms and nutrient pool for higher plants, and many others (Bieganowski et al., 2013; Paul, 2014). Also, soil organic matter itself is a sink for carbon dioxide and has a great potential to sequestrate this from the air. Pools of carbon bound in soil organic matter (especially in forest soils) are the largest of all compartments of the environment, and are estimated at 2500 Pg, that is nearly four times larger than the biotic, and three times larger than atmospheric carbon pools (Lal, 2004). Thus, soil organic carbon (SOC) circulation in ecosystems has become a topic of international interest, particularly in the context of long-term climate change (Bu et al., 2012; Degórski, 2005; Leifeld et al., 2013). The carbon pool in the atmosphere is much smaller than in the soil and even a relatively small change in global carbon quantity in the soil may have a considerable effect on the carbon concentration in the atmosphere (Schlesinger, 2000). Therefore, increasing SOC pools may have a crucial role in the capture and retention of CO_2 from the air, and thus in alleviating expected climate changes (Lal, 2004; Wan et al., 2011).

The content of organic carbon in ecosystems is considered as being in balance between carbon accumulated in soil, aboveground biomass, and atmosphere. The SOC pools are largely determined by the regional climate, vegetation, soil parent material, soil texture (Bockheim and Munroe, 2014; Egli et al., 2007; Johnson et al., 2011; Klopfenstein et al., 2015; Li et al., 2010; Labaz et al., 2014), and time (Egli et al., 2012; Kabala and Zapart, 2012). Human impacts, expressed as land use changes, usually lead to a reduction in the SOC content and an increase in greenhouse gas emissions (Batjes, 2011; Falahatkar et al., 2014; Galka et al., 2014b; Martin et al., 2010; Oktaba et al., 2014; Su et al., 2015). It is suggested that the CO_2 increase in the atmosphere can be reduced

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by carbon sequestration in soils through intelligent farming and forest management systems (Wasak and Drewnik, 2015).

The mountain ecosystems in boreal and temperate climate zones are most affected by climate change (Hagedorn et al., 2010). One aspect of these changes is a reduction of the soil organic matter content. Mountain soils are often referred to as shallow and skeletal, thus organic matter content is particularly important for soil fertility and the efficient functioning of ecosystems (Galka et al., 2013; Prietzel and Christophel, 2014; Szewczyk et al., 2015). The overall impact of individual environmental factors on the content of organic carbon in the soil is well-known, whereas the effect of the simultaneous impact of natural and anthropogenic factors on the amount, diversity and spatial dynamics of carbon pools in the soils of mountain areas is still underestimated (Degórski, 2005; Hagedorn et al., 2010). Analysis of the dynamics of SOC pools in mountain soils is complicated by the zonality of vegetation and climate, accompanied by the vertical diversity of soils and soil biological activity (Ghosh et al., 2014; Jobbágy and Jackson, 2000; Józefowska and Miechówka, 2015; Ma et al., 2016). Due to the relatively homogeneous geological soil substrate (granite) and vegetation zonality typical for temperate climates, the Karkonosze Mountains offer advantageous conditions for studies on the environmental effects of climate change and human influences. Moreover, most of the Karkonosze Mts area is under legal protection on both sides of the Polish-Czech border (bilateral national park). The Karkonosze Mts have a relatively well-recognized spatial soil pattern (Bojko and Kabala, 2016; Kabala et al., 2013a) and genesis of soil cover (Kabala et al., 2010; Waroszewski et al., 2010, 2013, 2016), as well as a history and distribution of soil contamination (Glina and Bogacz, 2012; Kabala and Bojko, 2014; Kabala and Szerszen, 2002; Szopka et al., 2013; Waroszewski et al., 2009). There are also numerous reports on the soil organic matter, but these are mainly focused on the structure and composition of humic substances (Jamroz et al., 2014; Licznar et al., 2008; Licznar et al., 2008; Labaz et al., 2012). Unfortunately, any model for SOC pools in relation to climate and vegetation gradients has not yet been developed. Meanwhile, such a model should be a starting point for a geoecological analysis, including the further effects of climate change and the changes in management of environmental resources (Brevik et al., 2016).

The first aim of the study was to determine the SOC pools in the mountain soils in relation to climate - altitude gradients, taking into account the vegetation zonality and human impact on the structure of vegetation cover. The crucial objective was to estimate the direction and extent of expected changes of SOC pools in the mountain soils in accordance with further simultaneous climate and land use changes, including the reconstruction of the mountain forests. An additional objective of this work was to analyse whether the humus form, which is an easily recognisable morphological reflection of the current dynamics of ecosystem, reflects the SOC pools in the mountain soils of the temperate zone.

2. Materials and methods

2.1. Area of study

The study was carried out in the Karkonosze Mountains, located in Central Europe, SW Poland (Fig. 1). The Karkonosze Mts are the central and highest range of the Sudeten Mountains (the highest peak – Mt. Śnieżka, 1602 m a.s.l.). The main part of the range is built of Carboniferous granites upraised during the Variscan orogeny. On the sides of the main massif, various Palaeozoic metamorphic rocks occur, including gneiss, mica schists, dolomites and greenstones (Aleksandrowski et al., 2013).

The Karkonosze Mts are subject to a suboceanic, temperate climate, with a significant impact of continental air masses. The spatial and temporal variation of climatic conditions in the Karkonosze is a result of geomorphological factors (including an orographic barrier) and seasonal circulation of air masses. However, the main feature of the local climate is a constant altitude-dependent zonal differentiation. The mean annual air temperature decreases from 7.9 °C in the foothills (ca. 550 m a.s.l.) to 0.4 °C on the top of Mt. Śnieżka (1602 m a.s.l.). The decrease in temperature with increasing altitude is very clear and reaches 0.6 °C per 100 m of elevation. The mean annual precipitation increases from 700 to 750 mm in the foothills to approx. 1500 mm in the uppermost zone. The duration of snow cover ranges from 60 to 65 days in the foothills, 140 days at an altitude of 1000 m a.s.l., to 180–200 days at the upper forest limit (Gramsz et al., 2010; Sobik et al., 2013).

Five climate - vegetation zones were distinguished in the Karkonosze Mts, typical to the medium and high mountains of Central Europe; however, land use and forestry have strongly impacted the current structure of the vegetation associations. Semi-natural broadleaf forests of the sub-mountain zone (<500 m a.s.l.) cover only small areas due to their cutting-out for agriculture or conversion to fast-growing spruce forests (Danielewicz et al., 2013). In the lower mountain forest zone (500–1000 m a.s.l.), the beech and mixed beech-fir native forests have also in large part been replaced with Norway spruce monocultures. The upper mountain forest zone (1000–1250 m a.s.l.) is, due to climate conditions at this elevation, naturally dominated by a *Calamagrostio villosae-Piceetum* community with Norway spruce as the prevailing tree species. The sub-alpine zone (1250–1450 m a.s.l.) is covered with a mosaic of mountain pine (*Pinetum mugo sudeticum*) shrubs and matgrass-meadows (*Carici-Nardetum*) phytocenoses (Novák et al., 2010). The alpine zone (1450–1603 m a.s.l.) in the Karkonosze Mts occurs in only small areas around the highest peaks and is represented by herbaceous communities such as "sparse meadows" of mountain rush

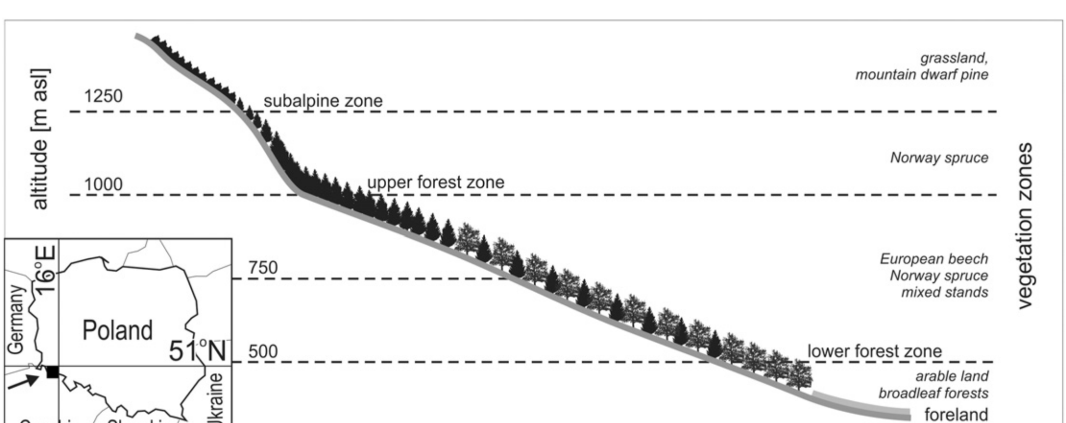

Fig. 1. Localization of the Karkonosze Mts and simplified slope cross-section with marked vegetation zones.

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