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Factors influencing humus forms and forest litter properties in the mid-mountains under temperate climate of southwestern Poland

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ABSTRACT

The conversion of spruce monocultures towards mixed and deciduous tree stands has been undertaken in central European countries, including south-western Poland. There is, however, still insufficient knowledge on the results of this transformation on the soil organic matter pools and humus forms. Thus, this study was focused on the relationship between altitude (a climatic factor), bedrock and soil type (trophic factors) and tree stand composition (a biotic factor steered by humans), and humus form, taking into account the forest litter and (mineral) humus horizon characteristics. The research was conducted as a part of environmental monitoring program in the Stolowe Mountains National Park (south-western Poland). Five aeromorphic humus forms (mull, moder–mull, moder, moder–mor, and mor) were noted in the soils of the Stolowe Mountains, and among them the mull, moder–mull and mor were distinctly correlated to specified sets of environmental factors. Litter thickness, SOC pools, and the concentrations of Pb and Cu increased with altitude and were higher on less fertile soils (Podzols developed from sandstone) under Norway spruce stands. Litter pH, in turn, decreased with altitude and was significantly higher on Eutric Cambisols and Luvisols under European beech stands. Among the compared environmental factors, bedrock geology was the least influencing factor, both on humus forms and forest litter characteristics, possibly due to the relatively small differences between the bedrocks (more or less acid regoliths, carbonate-free). Replacement of the Norway spruce by European beech will change the composition of forest litters and may transform the present-day moder and moder–mor humus forms into moder–mull and moder in those environments where spruce has previously been introduced in place of beech, against native soil trophic status. This transformation will restore natural ecological relationships in the forest ecosystems in south Poland and other Central European countries; however, it may reduce the topsoil organic carbon pools in the converted forest stands.

1. Introduction

Forest litter hosts numerous biological and biochemical transformations which are of such special significance for the functioning of forest ecosystems that all the phenomena related to organic debris decomposition in the litter are considered key processes occurring in the biosphere and affecting its biodiversity (Berg and McClaugherty, 2008). Organic debris reaching the forest floor (including the leaves, branches and bark of the trees, fruits, seeds and their covers, forest floor plants debris, as well as mushrooms and dead animals [Jonczak, 2013]) are subject to fragmentation processes, and then humification and mineralization, the rate of which depends on abiotic factors such as climate, altitude, and bedrock and soil type (Drewnik, 2006; Ponge et al., 2011; Vesterdal, 1999) as well as biotic factors, of which the most important are vegetation type and particular species composition (Albers et al., 2004; Blonska et al., 2013b; Brogowski and Czepinska-Kaminska, 2013; Fabiánek et al., 2009; Jamroz, 2012; McClaugherty et al., 1985; Paluch and Gruba, 2012; Peltier et al., 2001; Wolters, 1998) and soil micro- and macroorganism activity (Blonska et al., 2013a; Elmer et al., 2004; Kanerva and Smolander, 2007; Kubartova et al., 2009; Smolander and Kitunen, 2002). The equilibrium state between the rate of dead organic debris inflow to the forest floor and their transformation and mineralization determines forest soils properties (especially in the upper layers), including acidity (Hansson et al., 2011), stocks of organic matter (Berger et al., 2002; Kondras et al., 2012), nitrogen and other nutrients for the plants (Augusto et al., 2002; Borken and Matzner, 2004; Fujinuma et al., 2005; Prescott, 2002; Vesterdal et al., 2008), but also affects the intensity of soil mineral weathering (Augusto et al., 2000) and the direction and rate of soil-forming processes (Mareschal et al., 2010; Ranger and Nys, 1994). The transformations in the equilibrium state allow formation of a relatively stable litter, taking into account seasonal variability, characterized by specific thickness, morphology (layering and structure), and physicochemical properties (Ponge, 2003; Wälder et al., 2008). Special emphasis is placed on the role of forest litter, existing in the equilibrium state, as a global and local reservoir of organic carbon (Galka et al., 2014; Jandl et al., 2007), mechanical protection against water erosion (Kabala et al.,

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2013) and the filter accumulating atmospheric pollution (Szopka et al., 2011, 2013; Waroszewski et al., 2009), and thus hampering xenobiotic migration inside the soil profile and limiting toxicity for soil organisms and plants (Medynska-Juraszek and Kabala, 2012).

The balance between biomass inflow and its decomposition, both in litter and humus horizons, is affected by external environmental factors and also by basic soil properties and its biological activity which leads to the formation of a specific humus form (Ponge, 2003). The humus form is thus a synthetic effect of abiotic and biotic factor cooperation, and is a perfect indicator of habitat conditions (Ponge et al., 2002) and should be taken into account in an assessment of habitat quality for the ecologically-oriented forest management (Brozek et al., 2011; Wilson et al., 2001).

Most classifications distinguish three main humus forms in the soils of terrestrial ecosystems: mull, moder and mor (Broll et al., 2006; Green et al., 1993). They are differentiated in terms of micro- and macromorphological features in both organic and humus horizons, and to a high degree take into account the manifestations of the activity of soil organisms. Also, amphi and tangel forms, as well as intermediate forms (Boden Ad-hoc-AG, 2005, Jabiol et al., 2013), are often distinguished. The Polish Soil Classification (2011) distinguishes five humus forms in the forest soils (mull, mull–moder, moder, moder–mor, and mor). Their further classification is based on the degree of relative moisture regime (Ksero-, Droso-, Higro-, and Hydro- subtypes) and the composition or degree of development (humus varieties). Mull humus is characteristic for eutrophic habitats, where the rate of organic matter decomposition is very intense. Only an organic Ol horizon of a low thickness is observed on the soil surface over the humus horizon with a well formed granular structure and numerous coprolites, both in the A horizon and on the soil surface (Polish Soil Classification, 2011). Moder is observed in mesotrophic habitats, where a more important role in organic debris decomposition is played by fungi, and soil fauna is of a lower significance. The organic horizon is composed of subhorizons Ol and Of or Ofh, which are underlain by an acidic, but still structural, humus horizon. Mor humus is formed in oligotrophic habitats, where the rate of organic debris decomposition is the slowest, and epigeic earthworms are not observed. The organic horizon is composed of three subhorizons: Ol, Of and Oh, underlain by a thin and strongly acidic A horizon, often AE, or directly by eluvial EA horizon. Mull–moder and moder–mor humus forms have developed in transitional environments or under partial inconsistence of organic and humus horizon features, which may occur in cases of an intense forest management and on newly afforested post-agricultural soils (Classification of forest soils in Poland, 2000).

Soil humus is a very susceptible and dynamic soil element, quickly reacting to environmental changes, both natural and anthropogenic (Barbier et al., 2008; Berg and Meentemeyer, 2002, Galka and Labaz, 2014; Kawalko et al., 2011; Labaz et al., 2012; Prietzel and Bachmann, 2012), and therefore is included in all programs of natural environment monitoring (Bieganowski et al., 2013; Galka et al., 2014; Olsson et al., 2009; Schulp et al., 2008). There are also some suggestions to include humus form classifications to the standard soil description protocols (Broll et al., 2006; Jabiol et al., 2013; Zanella et al., 2011) and in an international soil classification WRB (IUSS, 2006), which would be a new impulse for detailed and common observations of soil humus state and possible changes.

Despite the fact that classification of humus forms has been included in Polish soil systematics and forest habitat evaluation since the 1980s, scientific publications concerning humus forms in the soils of Poland are very sparse, especially with regard to mountain areas (Galka et al., 2013). Therefore, an extensive study of the effect of biotic and abiotic factors on humus forms and physicochemical properties of forest soil organic layers has been undertaken within the program of the environmental monitoring in the Stolowe Mountains National Park (south-western Poland). The aim of this paper is an analysis of the effect of altitude (a climatic factor), bedrock and soil type (a trophic factor) and tree stand composition (a biotic factor steered by humans) on humus forms, including the characteristics of forest litter and humus horizons. Due to the character of the research program (environmental quality monitoring), the analysis also included the ability of organic horizons for trace element (Pb, Zn, Cu) accumulation.

2. Research area and methods

2.1. Research area

The Stolowe Mountains is a small range in the central part of the Sudeten Mts., localized in south-western Poland, bordering with the Czech Republic. Most of this area (6340 ha) is legally protected as the Stolowe Mountains National Park (SMNP), those areas in 90% is covered by forests (Jedryszczak and Miscicki, 2001). The Stolowe Mountains are characterized by diversified geology, including sedimentary and igneous rocks from the Paleozoic and Mesozoic eras (Kabala et al., 2011). The soil parent materials are: Carboniferous granitoids (11% of SMNP area), Permian sandstones (3%), Cretaceous sandstones (54%) and mudstones (31%), as well as Holocene alluvial and organic sediments (1%).

Altitude differentiation in the SMNP is within the range of 391 to 919 m ASL. Areas at a height of 700–800 m ASL (44%) and 600–700 m ASL (29%) are dominant, mainly in the central part of the massif. These areas form a kind of plateau of gentle slopes up to 10° (52% of the total area). 10–20° slopes cover 26% of the area, while those >20° occupy another 22% (Migoń et al., 2011).

Soil cover in the Stolowe Mountains is of a stripe-insular character and in general outline it refers to the geological structure. Dominant soil types (IUSS, 2006) include: Dystric Cambisols (32%), Eutric Cambisols (9%), Luvisols and Albeluvisols (15%), Podzols (31%) and Leptosols (4%). Other area is occupied by Gleysols, Histosols, Fluvisols and Technosols (Galka et al., 2013; Kabala et al., 2011).

A regular, planned forest management in the Stolowe Mountains started in the 18th century, and it was focused on an intensive timber production for glass and iron smelting. Natural mixed spruce-beech-fir stands have been successively replaced with pure spruce stands of a higher productivity. Currently, spruce dominates in 83% of the stands; however its contribution estimated based on habitat conditions should not be more than 26% (Jedryszczak and Miscicki, 2001). The second most frequent species is beech (8%), the desired coverage of which is estimated at 51%. Other species form only small admixtures or insular monocultures: birch (3%), larch (3%) and maple, ash, pine, black alder and oak (3% in total).

2.2. Research methods

The monitoring program aimed at assessing of the state of the natural environmental in the SMNP, with special attention paid to tree stands, was initiated in 2008. 398 round monitoring plots were established in a 400 × 400 m grid (centroids) “fitted” into the grid of large-scale forest monitoring in Poland. Smaller coaxial circles of a diameter of 8 m around the centroid were to collect soil samples and the larger (diameter of 25 m) for forest stand examinations. The field works conducted in the years 2009–2011 involved measurement and estimation of environmental parameters including: coverage with rocks and blocks, bedrock type, soil type, dominating and co-dominating tree species, understory and forest floor vegetation, and humus forms, including the thickness, structure and composition of the litter layers and macromorphological properties of humus horizon (criteria for humus form recognition are listed in Table 1). The samples were collected on 365 forested plots using the methods developed for the previous monitoring programs in the Sudeten Mts. (Karczewska et al., 2006; Szopka et al., 2011). Bulk litter samples (except the fresh fall) were collected using a stainless-steel cylinder of a diameter of 17 cm, which allowed an estimation of organic matter stocks per area unit. The representative mean sample