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Diversity of forest soils and bedrock in soil regions of the Central-European highlands (Czech Republic)

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ABSTRACT

Soil and bedrock influence ecosystem diversity through various means. The aim of this study was to typify forest soil catena diversity (FSCD) in the Central-European soil regions of the Czech Republic for ecosystem restoration planning. Typification was carried out through cluster analysis on Shannon-Wiener' indexes of soil and bedrock diversities and of terrain. The relationships between soil and ecosystem diversity were distinguished by employing linear regression confidence intervals. Flat, hillycountry and broken soil body combination groups (SBCGs) and eight FSCD types were defined at Central-European conditions. The FSCD types are divided into areas of lower pedodiversity in hillycountry SBCG and those of higher pedodiversity in flat and broken SBCGs. Primary distinguishing features of hillycountry SBCG are below-average soil diversity and below-average altitudinal differences. Clusters of flat or broken SBCGs are subdivided by average or above-average soil diversities and below-average or above-average altitudinal differences, respectively. Soil diversity is directly correlated with the size of the soil region, its total altitudinal difference, bedrock diversity and perimeter structure integrity. Soil diversity higher than bedrock diversity prevails in the Czech forests. Soil regions have higher differences in diversities of soil and bedrock. FSCD types have higher soil diversity values but lower differences in contrast to those of bedrock. Flat FSCD covers 45% of the total area, while hillycountry FSCD only covers 6% and broken FSCD covers 49%. Low FSCD covers 48%, medium FSCD covers 18%, and high FSCD covers 34%. > 52% of Czech forests, but 47% with medium up to high FSCD, have a close relationship of higher soil diversity and lower bedrock diversity. Close link between soil and bedrock suggests common framework of ecosystem restoration in forested as well as forestless land.

1. Introduction

Forest soil diversity (pedodiversity) is heterogeneity of soil properties due to soil development and forest management. Soil development is the result of differentiation of a soil body from the bedrock due to antagonistic accumulation, erosion and mass transformation (Hole and Campbell, 1985). Soil differentiation from bedrock can be natural or regulated. However, the link between the soil and the bedrock (soil–bedrock link) cannot be considered a component of ecosystem restoration planning. The soil–bedrock influence on ecosystem restoration is observable via typification of the pedo- and permanent abiotic component diversity (geodiversity) relationships (Ibañez and Feoli, 2013). There are different ways in which the ecosystem can be used to regulate soil development of forest, agricultural or urban pedodiversities (Daily, 1997). Forest soils of natural occurrence represent natural pedodiversity. While natural pedodiversity is divided into catenas, regulated pedodiversity is preconditioned by the structure of cultural landscape. Forest management preserves natural pedodiversity; alternatively, it increases pedodiversity disturbance of former agricultural or urban soils (Barbati et al., 2007). Disturbance of natural pedodiversity exists within the simplification of bedrock, soil and ecosystem interrelationships. Pedodiversity increase depends upon the increase of spatial disparities between the fertility of dead organic matter and the bedrock (Huggett, 1998). The comparison of pedo- and geodiversity between forested and deforested parts of soil catenas suggest in which parts does the ecosystem restoration framework differ (Amundson et al., 2003; Guo et al., 2003; Ibáñez et al., 2012).

Soil catenas are a unique link of pedo- and ecosystem diversity (ecodiversity) limited by specific bedrock type. Spatial soil catena units are both repeatable and unrepeatable. The unrepeatable soil catena units consist of soil regions and biogeographical provinces. The repeatable soil catena units consist of terrain and bedrock (Villela et al.,

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2013). Regions comprising of several bedrock types are distinguished by soil catena diversity conditioned via a unique geo-, pedo- and eco-diversity link. Pedodiversity types are repeatable within the limits of the unrepeatable unit (Ibáñez et al., 2012). Mean taxonomic distances and soil cover complexity (SCC) characterize pedodiversity. The mean taxonomic distance is a relative difference of soil properties within a catena (Minasny et al., 2010). SCC expresses the nature of the soil and ecosystem diversity link (Ibañez et al., 1995). The pedo- and geodiversity links determine the total ecodiversity, but their relationship is divergent in tropical and temperate conditions. Ecodiversity is directly correlated to geodiversity in temperate conditions, whereas the two diversities are indirectly correlated in the tropics (Barthlott and Mutke, 2000). Geodiversity influences the soil–bedrock link proximity more than land use variability (Ives and Carpenter, 2007). Close links between the soil and the bedrock in close-to-natural ecosystems point to soil–bedrock links in changed ecosystems of identical natural catena (Galvão et al., 2008). Similar soil and bedrock diversities influence terrestrial ecosystems differently than dissimilar soil and bedrock diversities (Huggett, 1998). Prevailing inconsonances of the soil diversity and the bedrock state are caused by ecological disturbances (Villela et al., 2013). The magnitude of the ecological disturbance effect on soil development increases with altitude (Minasny et al., 2010). Even so, the differences between soil and bedrock properties are more severe in areas of lower geodiversity exhibiting a prevailing mass accumulation and are less severe in areas of higher geodiversity exhibiting erosion prevalence (McLeod et al., 2008). Long-range transport of weathered cover into accumulation areas increases the differences between soil and bedrock. In contrast, the weathered cover is transported over shorter distances in mountainous areas, therefore, the soil and bedrock differences remain small (Solomeshch, 2005).

The study aims to define forest soil catena diversity and to derivate the relationship with total ecodiversity between forested and deforested territories. The pedodiversity and total ecodiversity relationship inside catena is conditioned by terrain characteristics. Mutual features of soil, bedrock and terrain composition suggest limits in similarity between repeatable and unrepeatable catenas (Guo et al., 2003). Ratio between forest soil diversity and the area of the investigated territory indicates either a large-scale or a small-scale soil representation (Minasny et al., 2010). Ratio of forest soil diversity and altitudinal difference of the investigated territory indicates vertical preconditions of soil catena occurrences (McCoy and Bell, 1991). Ratio of forest soil diversity and the perimeter structure of the investigated territory indicates level of soil catena transition structure. Provided that the soil–bedrock links at a catena are sufficiently close, they indicate mutual pedodiversity of forests and deforested parts. If the soil–bedrock links at a catena are not sufficiently close, the pedodiversity of the forests and the forestless areas is variable (Huggett, 1998).

2. Material and methods

Forest soil catena diversity (FSCD) types were derived using typification and SCC analysis. The typification consists of overlay and statistical analyses of soil, bedrock and terrain characteristics composition in soil regions (Ibañez et al., 1998). The terrain characteristics of the area, the altitudinal difference and the perimeter structure integrity were employed to indicate the influence on the soil–bedrock link (Hopp and McDonnell, 2009). The SCC was obtained by overlapping linear regression confidence interval and soil–bedrock link difference. The confidence interval suggested, where ecosystem diversity of forested and forestless land is similar (Amundson et al., 2003). The difference suggested a direct or indirect correlation between the soil and the total ecosystem diversity (Ricklefs and Schluter, 1993).

2.1. Soil geographical framework

The forest soil properties were divided into repeatable and unrepeatable catenas. Repeatable catena composition inside a soil region was used as a variable for typification (Guo et al., 2003). Soil region is the smallest unrepeatable soil catena unit with a unique configuration of geo-, pedo- and biodiversity (Ibáñez et al., 2012). Soil associations and soil body combinations (SBCs) are basic repeatable units with characteristic inner configurations of terrain and bedrock abiotic components (Pelíšek and Sekaninová, 1975; Demek, 1987; Macků and Homolová, 2007). The soil association is the composition of the major soil group matrix and the arrangement of soil group facets. The SBCs are the arrangements of soil associations in terrains with similar topography and bedrock (Hole and Campbell, 1985). The areas of forest soil associations and bedrock types were used for the calculations of forest soil diversity indexes. The SBCs were used for the characterization of forest soil catena diversity types.

2.2. Investigated area

Forest soil typification was carried out within the Czech Republic soil regions. The Czech Republic (CR) is a Central-European country covering the core of the Bohemian Massif (Hercynian system), the north border of the Vienna Basin, and the Outer Western Carpathians (Alpine-Himalayan system) (78,866 km^2, 115–1602 m a.s.l.). Potential natural forest cover of the CR is 98%, whereas the present-day forested area is 34% (Barbati et al., 2007). Soil environment of the CR includes 23 unwaterlogged bedrock types, 8 waterlogged bedrock types, 12 major soil groups, 55 soil associations and 13 soil body combinations (Culek et al., 2005). Major soil groups, including Cambisols, Luvisols and Chernozems, cover over 80% of the CR (Bukovský et al., 2012). Podzols, Fluvisols and Phaeozems are found as associated major soil groups. Czech forests predominantly occur in sloped terrains (18%), highlands (13%), and mountains (2%), as well as on ridges (5%). Deforested areas predominantly occur in depressions (8%), in floodplains (6%), on broken plateaus (39%), on hillycountries (11%) and in flat terrains (23%). Forests in the CR are preserved predominantly on loess loams (20%), acid metamorphids (17%), granite (8%), loamy gravel-sands (5%), granodiorites (5%), sandstone flysch (5%), block sandstone (4%), loamy floodplain sediments (5%) and acid waterlogged sediments (8%). Forests overlie 53 soil associations and all existing SBCs (Macků and Homolová, 2007). Two associations occur exclusively outside forest soils, and on the contrary, six associations occur almost strictly under forest cover. Vertisol and Haplic Phaeozem associations occur solely on agricultural soils; conversely, Histosols, Gleysols and the majority of Podzol associations occur only within forests. The total number of 339 soil regions are organized into three geographical tiers of floodplains, hillycountries and highlands (Němeček and Tomášek, 1983; Němeček and Kozák, 2003).

2.3. Data

The basis for forest soil typification consists of soil catena vector layers and a raster terrain model. The soil catena layers included soil regions and repeatable units. Borders of forested/forestless land and soil regions were used for the division of the repeatable units in the regional forest development plan (RFDP) and biogeographic registry databases (Tomášková, 2004; Vlčková et al., 2015). Soil regions were obtained from regional soil cover units of the CR (Němeček and Tomášek, 1983). The map scale of the soil regions was 1:500000. SBCs, soil associations, and bedrock types characterized the repeatable catena units. The SBCs were obtained by overlaying terrain and bedrock types among the soil regions (Table 1). Polygonal bedrock types were taken from biochore classifications (Culek et al., 2005). The map scale of the bedrock types was local 1:50000. Terrain model was calculated by generalizing discrete point altitudes to within 10 by 10 m cells in the Basic Base of Geographical Data of the Czech Surveyor and Cadastral Administration (Čada and Šilhavý, 2013). Polygonal soil associations were taken from an overlay of generalized physical-geographic