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Pedodiversity and its controlling factors in mountain regions — A case study of Taihang Mountain, China

Tonggang Fu[a], Lipu Han[a], Hui Gao[a,b], Hongzhu Liang[a,b], Xiaorong Li[a,b], Jintong Liu[a,*]

[a] Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050022, China

[b] University of Chinese Academy of Sciences, Beijing 100049, China

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ABSTRACT

Knowledge on pedodiversity is crucial for the management and protection of soil resources. However, little is known about the controlling factors of pedodiversity, especially in mountain regions with a highly heterogeneous environment. This paper analyzed pedodiversity (soil taxa diversity) and the influencing factors in Taihang Mountain region in China. The richness (S), Menhinick's index (M), Shannon index (H), maximum Shannon index (H_{max}) and evenness index (E) were used to explain pedodiversity in the study area. The influences of natural factors (including elevation, slope gradient, precipitation and temperature) and anthropogenic factors (including population density and percentage of farmland) were analyzed using partial correlation analysis and canonical correspondence analysis. The results showed that for the 101 counties in Taihang Mountain, average H was 1.69, which suggested a relatively low pedodiversity (normal H range is 1.5–3.5, and rarely exceeds 4.5) in the study area. Logarithmic normal distribution had the best fit for the abundance distribution model, indicating that intermediate abundance of soil type was most common. The best fit Logarithmic function was for the relationship between richness and area. Soil taxa richness increased significantly for areas less than 1000 km^2, but increased gradually for areas larger than 1000 km^2. This suggested that 1000 km^2 was the breakthrough point on the richness-area curve, and that the effect of area on pedodiversity could be negligible for regions larger than 1000 km^2. Canonical correspondence analysis showed that the influence of these factors on pedodiversity decreased in the order of: elevation > percent farmland > slope gradient > population density > precipitation. This suggested that elevation and farming had the highest effect on pedodiversity. The study provided further insight into pedodiversity in mountain regions, which is critical for the protection of soil resources and pedodiversity.

1. Introduction

Pedodiversity, or simply soil diversity, is used to explore, quantify and compare the complexity of soil patterns in different units and thereby provides the basis for biodiversity (Ibañez et al., 1995; Tennesen, 2014; Amundson et al., 2015). Pedodiversity could be divided into taxonomic pedodiversity, functional pedodiversity, genetic pedodiversity and soil property diversity (Saldaña and Ibáñez, 2004; Ibáñez et al., 2005; Kooch et al., 2015). The study of pedodiversity can be done at different scales, including polypedon, association, landscape, drainage basin and geographical scale of soil (Ibañez et al., 1995). A thorough understanding of pedodiversity is helpful in both soil management and soil protection, and can also be applied in the protection of biodiversity (Tennesen, 2014; Rannik et al., 2016). Compared with biodiversity, however, research on pedodiversity is very limited, despite the stress for pedodiversity research in different regions (Guo et al., 2003; Saldaña and Ibáñez, 2004; Shangguan et al., 2014).

The definition of pedodiversity first appeared in the 1990s (Mcbratney, 1992; Ibañez et al., 1995; Ibañez et al., 1998) and pedodiversity has since gradually gained interest in Spain, America, China and other countries (Amundson et al., 2003; Tan et al., 2003; Saldaña and Ibáñez, 2004; Toomanian et al., 2006; Minasny et al., 2010; Lo Papa et al., 2011; Ren and Zhang, 2015). Recently, books (Ibáñez and Bockheim, 2013) and special issues (Volume 135, Issues 3–4, Pages 213–352, 15 December 2011, *Geomorphology*) have been set up focusing mainly on pedodiversity. In Google Scholar, the search results of “pedodiversity/soil diversity” increased significantly from the 1990s (458) to the 2010s (3356). These existed researches on pedodiversity

* Corresponding author at: Key Laboratory of Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, 050021 Shijiazhuang, China.

E-mail address: jtliu@sjziam.ac.cn (J. Liu).

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focused mainly on pedodiversity index, richness-area relationship and rare/endangered soil taxa at different scales. For example, Ibañez et al. (1995) proposed three ways to describe pedodiversity, including richness, abundance distribution models and indexes based on proportional abundance. Since then, these methods have been widely used (Saldaña and Ibáñez, 2004; Krasilnikov et al., 2009; Lo Papa et al., 2011; Costantini and L'Abate, 2016). Richness-area relationship has always been studied in conjunction with abundance models, both of which reflect the distribution of the individuals of different soil types (Ibáñez et al., 2005; Feoli et al., 2007). The loss of pedodiversity is also important phenomenon that has been studied. Spain, America, China and other countries are threatened by pedodiversity loss, and rare and endangered soils have been identified for these regions (Amundson et al., 2003; Guo et al., 2003; Shangguan et al., 2014; Tennesen, 2014). Until now, these aspects of pedodiversity have been well studied. However, what is not clear is the factors which control pedodiversity in a given region.

Based on several studies, the main factors controlling pedodiversity include natural factors (e.g., geomorphology, meteorology, etc.) and anthropogenic factors (e.g., farming, urbanization, etc.). Geomorphology is an important factor, and mountain regions generally have higher pedodiversity than plain regions (Ibáñez and Feoli, 2013; Costantini and L'Abate, 2016). In addition, pedodiversity in transition zones (zones between different land use types or landforms) are higher than in non-transition zones (Bockheim and Schliemann, 2014). Meteorology also influences pedodiversity, and low pedodiversity is often associated with low or high rainfall/temperature (Minasny et al., 2010). Besides natural factors, agriculture and urbanization (which reflect human activity) are also important influencing factors of pedodiversity (Guo et al., 2003; Tennesen, 2014). Moreover, the controlling factors of pedodiversity can be different for different soil hierarchies. For example, soil diversity is mainly controlled by bioclimatic and hydrologic factors at high classification levels, but by parent material, topography and hydrological conditions at low levels (Shangguan et al., 2014). Although numerous factors were studied on pedodiversity, most are still described qualitatively. Quantitative analysis of the factors and ranking of their importance are critical for an in-depth understanding of pedodiversity for use in soil protection and management.

Taihang Mountain in North China is a north-northeast range of mountain belt and is an important transition zone between the Loess Plateau and North China Plain (Wang and Li, 2008). Mountain regions, as noted by Costantini and L'Abate (2016), generally have high pedodiversity. Moreover, transition zones often have high pedodiversity (Bockheim and Schliemann, 2014). Considering these conditions, Taihang Mountain should have high pedodiversity. However, because of overexploitation of natural resources and excessive disturbance by local residents, the Taihang Mountain ecosystem has degenerated significantly (Li et al., 2004). Thus soil loss has become a severe issue, with more endangered soil types in this region than in other areas of China (Shangguan et al., 2014). This makes it more significant to understand pedodiversity and the controlling factors in the fragile Taihang Mountain ecosystem.

Thus the objectives of this paper were to: 1) determine the spatial distribution of pedodiversity, 2) understand the richness-area relationship, and 3) quantify and rank the influencing factors of pedodiversity in Taihang Mountain region.

2. Materials and methods

2.1. Site description

Taihang Mountain (34°36′–40°47′N, 110°42′–116°34′E), which is located in North China (Fig. 1), is the natural boundary between the Loess Plateau and the North China Plain. It extends from the northeast to the southwest for an area of 120,000 km^2 and stretches across five administrative regions, including Beijing, Hebei province, Shanxi province and Henan province. Taihang Mountain has a highly heterogeneous geological setting. Because of the orogeny, the western and eastern parts of the mountain have very different structural evolution, sedimentation and tectonic settings (Wang and Li, 2008). The average elevation of Taihang Mountain is 1000–1500 m, which decreases from the northwest to the southeast. The highest elevation (2882 m) is in the northern part of the mountain at Xiaowutai.

The climate is the East Asian Monsoon type which is characterized by warm, rainy summer and cold, dry winter. The average annual (2005–2014) precipitation is 456.57 mm and the annual mean temperature is 11.36 °C. Both precipitation and temperature decrease from the southeast to the northwest. The mean precipitation for the southeast and northwest parts of the study area are 617.23 mm and 385.08 mm, with corresponding mean temperatures of 12.95 °C and 7.65 °C, respectively. Due to precipitation and temperature gradients, the heterogeneity of the vegetation decreases from the north to the south. In addition, the vegetation patterns are significantly affected by topography, elevation, slope and aspect as well as the interactions between these environmental factors (Zhang et al., 2006). Soils in Taihang Mountain developed mainly from limestone in the northern and southern parts, but from gneiss in the middle region. Moreover, the soils in the region are thin with abundant rock fragments. Based on data from an experimental site located in the middle region of the study area, the average soil thickness is 35 cm with above 0.1-cm rock fragment content of 21.4% (Cao, 2011).

Taihang Mountain region contains 101 counties. The environmental and human-related conditions in this region are summarized in Table 1. In the table, mean elevation denotes the average elevation for each county. The range of elevation (i.e. elevation range in Table 1) for each county is calculated by subtracting the minimum from the maximum elevation. The means and ranges of other factors were calculated in the same way.

2.2. Pedodiversity indexes

The indexes used to describe pedodiversity can be divided into three main categories (Ibañez et al., 1995). The first is the richness index (S), which is the number of objects (i.e., soil types) within a region of interest. Richness index only focuses on the number of objects and largely ignores the number of individuals (N, i.e., the area of the soil types) in the region. Therefore, derived parameters based on richness are also used. Menhinick's index (M), for example, can be calculated from S and N as (Menhinick, 1964):

$$\mathrm{M} = \frac{S}{\sqrt{N}} \quad (1)$$

The second category used in pedodiversity analysis is abundance distribution model, which describes the distribution of the object abundance. The abundance model is a histogram in which the X-axis is the rank of the object abundance from maximum to minimum and the Y-axis is the logarithm of the abundance. Four models are widely used in this simulation model — geometric model (which suggests that a few objects are dominant), broken stick model (which gives an even distribution of the objectives), and logarithmic model and log normal model (both of which show that intermediate abundance objects are dominant). The detailed formulas for these models are given by Ibáñez et al. (2005). Each of the abundance models gives one type of richness-area relationship and are widely used in both biodiversity and pedodiversity. For example, the broken-stick and lognormal models output power curves, but the geometric and logarithmic models output logarithmic curves for richness-area relationships.

The third category of pedodiversity indexes is based on proportional abundance of objects. The Shannon index (H) belongs to this category and is given as: