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Short communication

On measuring pedodiversity

Alex McBratney *, Budiman Minasny

Faculty of Agriculture, Food and Natural Resources, The University of Sydney, NSW 2006, Australia

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Abstract

Measures of taxa pedodiversity are discussed. It is argued that taxonomic distance needs to be incorporated into pedodiversity calculations to get an effective estimate. Various comparisons showed that the mean taxonomic distance, also called Rao's quadratic entropy, appears to be a good measure of pedodiversity. This index combines both information on the abundance and taxonomic distance between soil types.

Keywords: Pedodiversity; Soil variation; Taxonomic distance; Diversity indices; Shannon's entropy; Simpson's diversity

1. Introduction

Pedodiversity is a way of measuring soil variation (McBratney, 1992) usually using taxa.

Notwithstanding the difficulties of concepts of individuals and species for soil, soil scientists have pragmatically adapted the concept of biodiversity and used indices such as Shannon's index using taxa from well-accepted international soil classification systems (Ibáñez et al., 1995; Ibáñez et al., 1998; Martín and Rey, 2000; Guo et al., 2003; Phillips and Marion, 2005).

This paper gives a rationale for pedodiversity measurement. It aims to introduce new measures of pedodiversity which take into account both information on the relative abundance and also the taxonomic differences between soil classes, and to compare these measures with a number of well-known diversity indices.

McBratney (1992) defined pedodiversity and claimed a need for it in terms of soil preservation. Pedodiversity can be generally defined as the variation of soil properties or soil classes within an area. Ibáñez et al. (1995) first introduced well-established ecological diversity indices as measures of pedodiversity. They include richness, abundance, and proportional abundance. Richness is the number of different soil types, which is the number of soil classes at particular level in a taxonomic system. Abundance is defined as the distribution of the number of soil individuals, and the relative abundance is the relative area occupied by each soil type. Ibáñez et al. (1998) took a further step by calculating the diversity indices for continents based on the FAO Soil Map of the World. Soil richness and area relationship that describe the number of soil types in a given area, which came from biodiversity analysis, were also adapted to soil studies. Beckett and Bie (1978) showed that the number of soil types encountered in soil surveys increased with the size of area surveyed. The relationship between number of soil classes (diversity) and area is also shown by Caniego et al. (2006), Guo et al. (2003), Ibáñez et al. (1998), and Phillips and Marion (2005). McBratney et al. (2000) using the data of Ibáñez et al. (1998) plotted the diversity against the area for each continent; they showed that some continents (such as Australia) are less diverse than others (such as South and Central America).

Guo et al. (2003) studied pedodiversity in the USA. They calculated Shannon's entropy for various taxonomic levels (according to the USDA Soil Taxonomy), from order to suborder, great-group, sub-group, family, and series. They showed that taxonomic richness and Shannon's entropy increase with increasing level of taxonomic division. Since we are dealing with the same soil covers increasing the level of taxonomic division should not increase the diversity significantly. The increase is because conventional diversity measures only consider the relative abundance of soil classes.

* Corresponding author. Tel.: +61 2 9351 3214; fax: +61 2 9351 3706.
E-mail address: a.mcbratney@usyd.edu.au (A. McBratney).

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2. Rationale

Diversity is a measure of variation. Natural pedodiversity is a function of soil formation. Observed pedodiversity which attempts to estimate the natural pedodiversity is a function of: (a) the soil individual chosen, (b) the region or area of interest, (c) the taxonomic system used, (d) the level in the taxonomic system, and (e) the index of diversity. The natural pedodiversity is constant so (a), (b), and (c) being equal we would like a measure that assesses the diversity. Changing levels in a taxonomic system leads to more taxa but the intrinsic pedodiversity is constant — so number of taxa alone will not be a measure of diversity. As we descend the taxonomic system we introduce more properties so hopefully we obtain a more precise estimate of pedodiversity. The estimate should be closer to the true value. Unfortunately many measures of diversity increase when descending the taxonomic hierarchy. This is unreasonable because soil does not appear to have natural species — we are simply trying to capture pedological variation. One way of doing this is to take the distance between taxa into account. As one descends the hierarchy the distance between neighbouring taxa will decrease but the overall distance should be about the same (otherwise the hierarchy isn't working properly, i.e., the lower level taxa are not true subsets of the higher level ones). This suggests that for soil, without recognizable species but with recognizable taxa at various levels in various taxonomic systems — we should have a measure that takes into account taxonomic distance.

Conventional diversity measures, such as Shannon's entropy or Simpson's diversity only measure the relative abundance of soil classes, and there is no information on the taxonomic similarity or differences between soil classes. Consider a hypothetical situation using the Australian Soil Classification System (Isbell, 1996) (Table 1). Site A has the following equal distribution of soil suborders: Brown Dermosols, Brown Chromosols, Brown Kurosols, Stratic Rudosols, and Redoxic Hydrosols. Site B has an equal distribution of the following suborders: Brown Dermosols, Red Dermosols, Brown Chromosols, Red Chromosols, and Brown Kurosols. Using Shannon's entropy both areas will have the same value of 1.61. Intuitively, site B is more diverse than site A as it consists of 5 soil orders, while site A only has 3 soil orders. This paper introduces new indices of pedodiversity which considers both information on the relative abundance and the taxonomic differences between soil classes. This is followed by examples and comparisons with conventional diversity indices.

3. Theory

3.1. Diversity measures

There are various ways of measuring pedodiversity, most of them are derived from biology ecology. They are:

- Richness

Richness s is simply the number of soil classes that exists in an area.

- Shannon's entropy or diversity index:

$$H = -\sum_{i=1}^{s} p_i \ln p_i \tag{1}$$

where p_i is the proportional abundance of class i. Minimum entropy occurs when one class dominates over the area, or $p=1$, $H_{\min}=0$. The closer the values of p to $1/s$, the more homogeneous the distribution of p, the more diverse is the class composition. The maximum value of H is defined as $H_{\max}=\ln s$, a value close to $H_{\max}$ indicates an even proportional contribution of every class (Martín and Rey, 2000). This index is the most commonly used measure of pedodiversity (Guo et al., 2003; Ibáñez et al., 1995; Ibáñez et al., 1998; Phillips and Marion, 2005).

- A measure of evenness can be defined as:

$$E = \frac{H'}{H_{\max}} = \frac{H'}{\ln s} \tag{2}$$

An area in which each soil type is equally abundant has high evenness, and an area in which the abundance of soil types differ greatly has low evenness.

- Simpson's dominance index, also called the Gini index:

$$D = \sum_{i=1}^{s} p_i^2, \tag{3}$$

with $0 \le D \le 1$, values near zero corresponding to a highly diverse system, and values near one corresponding to more homogeneous system.

Table 1
Hypothetical example of the soil distribution at sites: A, and B

	Brown Dermosol	Red Dermosol	Brown Kurosol	Brown Chromosol	Red Chromosol	Stratic Rudosol	Redoxic Hydrosol
p site A	0.2	0	0.2	0.2	0	0.2	0.2
p site B	0.2	0.2	0.2	0.2	0.2	0	0
Distance matrix △							
Brown Dermosol	0.000	0.258	0.408	0.408	0.483	0.516	0.966
Red Dermosol	0.258	0.000	0.483	0.483	0.408	0.516	0.966
Brown Kurosol	0.408	0.483	0.000	0.258	0.365	0.483	0.983
Brown Chromosol	0.408	0.483	0.258	0.000	0.258	0.483	0.983
Red Chromosol	0.483	0.408	0.365	0.258	0.000	0.483	0.983
Stratic Rudosol	0.516	0.516	0.483	0.483	0.483	0.000	1.000
Redoxic Hydrosol	0.966	0.966	0.983	0.983	0.983	1.000	0.000

The soil classes are suborders according to the Australian Soil Classification System. Also shown is the taxonomic distance between the soil classes.