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Biodiversity and pedodiversity: a matter of coincidence?

Biodiversidad y edafodiversidad: cuestión de coincidencia?
Biodiversidade ou pedodiversidade: questão de coincidência?

AUTHORS

Ibáñez J.J. [@ 1]
choloibanez@hotmail.com

Saldaña A. [2]

Olivera D. [3]

[@] Corresponding Author

[1] Centro de Investigaciones sobre Desertificación CIDE (CSIC, Universitat de Valencia, Generalitat Valenciana). Carretera Moncada-Náquera, Km 4,5. Apartado Oficial 46113. Moncada (Valencia), Spain.

[2] Departamento de Ecología, Universidad de Alcalá. Ctra. Madrid-Barcelona, Km 33.6. 28871 Alcalá de Henares (Madrid), Spain.

[3] Facultad de Ciencias Agropecuarias, Universidad de Sancti Spíritus José Martí Pérez. Avda. de los Mártires 360, esq. Carretera Central. C.P. 60100 Sancti-Spiritus, Cuba.

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ABSTRACT

The concept of diversity has been widely used in ecological studies, although mainly for the biotic component (biodiversity). Regrettably, the effects of abiotic structures (e.g. soils) on the biotic components of ecosystems, landscapes and biomes are still a matter of discussion. We examined the similarity and differences in spatial and temporal patterns between biodiversity and pedodiversity. This comparative study was possible because of the increased availability of digital data on soils and other natural resources at various scales for pedodiversity analysis using the same theoretical concepts and tools applied by ecologists for biodiversity analyses. Remarkably, the spatial patterns of pedogeographic units detected by pedologists are similar to those reported by biologists for a plethora of ecosystems.

RESUMEN

El concepto de diversidad es de uso extendido en la literatura ecológica, si bien suele hacer referencia a los componentes biológicos exclusivamente. Lamentablemente, los efectos de las estructuras abióticas (por ejemplo los suelos) sobre las entidades bióticas de los ecosistemas, paisajes y biomas aún son materia de incipientes debates. En el presente artículo se explican las similitudes y diferencias entre los patrones espaciales y temporales de los análisis de biodiversidad y edafodiversidad descritos en la bibliografía. Actualmente, este tipo de análisis comparativos no supone excesivas dificultades debido a la creciente disponibilidad de bases de datos digitalizadas, tanto de suelos como de otros recursos naturales, a diferentes escalas. Las herramientas conceptuales y matemáticas utilizadas en los estudios de edafodiversidad son las mismas que las empleadas por los ecólogos en el ámbito de la biodiversidad. Los resultados obtenidos hasta la fecha demuestran que los patrones espaciales de la edafodiversidad, detectados por los expertos de la ciencia del suelo, son similares a los obtenidos por los ecólogos para una amplia gama de ecosistemas y condiciones ambientales.

RESUMO

O conceito de diversidade tem sido amplamente utilizado em estudos ecológicos, embora principalmente na sua componente biótica (biodiversidade). Lamentavelmente, as repercussões das estruturas abióticas (e.g. solos) sobre os componentes bióticos dos ecossistemas, paisagens e biomas ainda são um assunto em debate. Neste estudo comparativo, examinaram-se as semelhanças e diferenças nos padrões espaciais e temporais entre biodiversidade e pedodiversidade, tendo-se tornado possível devido ao aumento da disponibilidade de dados digitais em solos e outros recursos naturais em várias escalas para análise da pedodiversidade usando os mesmos conceitos teóricos e ferramentas aplicadas pelos ecologistas para análise da biodiversidade. Curiosamente, os padrões espaciais de unidades pedogeográficas detectados pelo pedologistas são bastante semelhantes aos relatados por biólogos relativamente a uma infinidade de ecossistemas.

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1. Introduction

The concept of diversity has been widely used in ecological studies, although mainly for the biotic component (biodiversity) (e.g. Sugihara 1981; Magurran 1988). Regrettably, the impacts of abiotic structures (e.g. soils) on the biotic components of ecosystems, landscapes and biomes (the so-called "habitat heterogeneity" studies) are still a matter of discussion. Fortunately, a "paradigm shift" has occurred so that pedodiversity (Ibáñez et al. 1990, 1995) has caught scientists' attention (e.g. more than fifty papers on pedodiversity are available in literature) and new research possibilities in soil science are now available (Toomanian and Esfandiarpoor 2010). Pedodiversity has been shown to be a key aspect of biological heritage (i.e. preservation of biodiversity), cultural heritage (i.e. ancient and traditional sustainable practices), soil monitoring (benchmark soils in monitoring programs), prehistoric and palaeontological heritage (archive of artefacts and remnants of extinct species), biogeosphere heritage (archive of past environments), and geological heritage (pedodiversity is a part of the concept of geodiversity) (Ibáñez et al. 2012; Ibáñez and Bockheim 2013). Figure 1 shows the position of pedodiversity within the environmental sciences. The relationships between pedodiversity and the diversities of other natural bodies are shown in Figure 2. The objective of this work was to compare the spatial and temporal patterns between biodiversity and pedodiversity, with the support of the sciences of complexity, and to establish themes for future research. This comparative study was feasible due to the increased availability of digital data on soils and other natural resources at various scales for pedodiversity analysis using the same theoretical concepts and tools applied by ecologists for biodiversity analyses.

KEY WORDS
Soil diversity, biological diversity, abundance distribution models, spatial patterns

PALABRAS CLAVE
Diversidad de suelos, diversidad biológica, modelos de distribución de abundancia, patrones espaciales

PALAVRAS-CHAVE
Diversidade do solos, diversidade biológica, modelos de distribuição de abundância, padrões espaciais

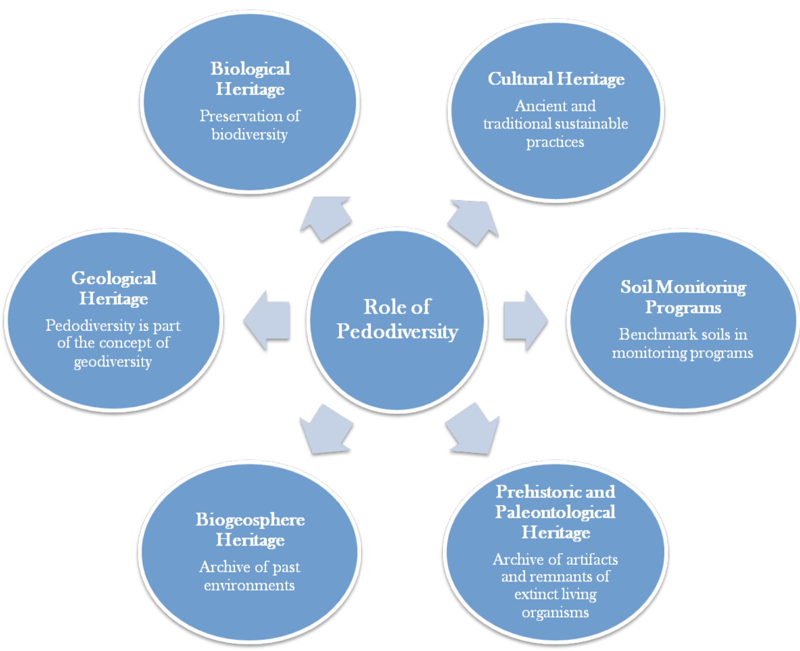

Figure 1. Pedodiversity: reasons for preservation of a pedological heritage.

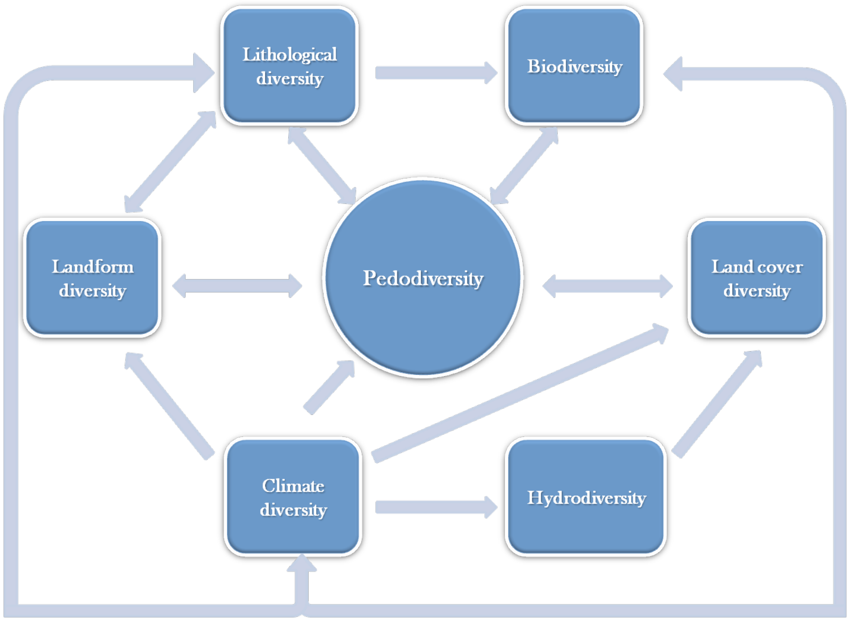

Figure 2. Relationships between pedodiversity, biodiversity, landform diversity, lithodiversity, climate diversity, hydrodiversity and land use diversity (soil forming factors).

Pedodiversity is conceptually defined as the inventory of the variety of discrete pedological entities, i.e. pedotaxa and pedogenetic horizons, as well as the analysis of their spatial and temporal patterns (Ibáñez et al. 1990, 1994). There are essentially two components of diversity: the variety of categories (or taxa), and the way in which the individuals are distributed among those taxa (evenness or equitability). Indices of diversity either incorporate both components of diversity into a single value, or less frequently, tend to neglect one of these components. Species diversity measures are divided into three main categories: species richness indices, indices based on the proportional abundances of species (e.g. the Shannon index) and species abundance models (Magurran 1988). Remarkably, Huston (1994) included soil types in the list of possible elements to calculate diversity indices. For any resource at a given taxonomic level, therefore, it is possible to study its taxonomic diversity.

Diversity analyses utilize mathematical tools which have been applied by ecologists for decades to analyze the intrinsic regularity of ecological entities. Remarkably, the spatial patterns of pedogeographic units detected by pedologists are rather similar to those reported by biologists for a plethora of ecosystems (e.g. Petersen et al. 2010). In summary, biological and pedological systems follow similar mathematical patterns of: (i) diversity; (ii) richness and diversity-area relationships; (iii) richness and diversity-time relationships (islands and terrace chronosequences); (iv) abundance distribution models; (v) taxa-range size distribution; (vi) nested subset analysis; (vii) fractal and multifractal analysis; (viii) complementarity algorithms for selecting areas to design networks of natural reserves, and (ix) mathematical structures of classifications (Ibáñez et al. 1990, 1994, 1995, 2005a,b; Ibáñez 2006; Phillips 2001; Caniego et al. 2006). Furthermore, predictions of the theory of Island Biogeography have been used to explain the pedorichness and soil assemblage analyses in archipelagos (Ibáñez and Effland 2011). These are intriguing facts that must be analysed in depth given that pedodiversity-area relationships cannot be explained using the biological assumptions proposed by MacArthur and Wilson (1967).

Abundance distribution models provide an opportunity to visually examine this extraordinary similarity. According to biodiversity experts, there is a sequential order of distributions starting with the geometric series that is the least equitable (i.e. a few objects are dominant while the rest are very rare), continuing to the logarithmic series and the log-normal distribution, and ending with the broken stick model (the most equitable). Most communities studied by ecologists display a log-normal statistical distribution (Sugihara 1981). A similar distribution applies to the pedodiversity of soil assemblages (Ibáñez et al. 1995, 1998, 2005a,b; Guo et al. 2003). Adjustments to geometric and logarithmic distributions have been observed in species-poor communities (generally under severe environmental stress) or in the first stages of ecological succession (e.g. Magurran 1988). The broken stick model, in contrast, is rare although some animal communities fit it well (MacArthur and Wilson 1967), as do pedotaxa distributions at a global scale (Ibáñez et al. 1998). Furthermore, it has been detected that in small or disturbed regions of pedogeographic units or soilscapes, pedotaxa distributions more closely fit geometric and logarithmic distributions than a log-normal distribution (Ibáñez et al. 2005a), similar to that predicted by the ecological literature for living organisms. Using abundance distribution models thus allows us to detect similar patterns in biodiversity and pedodiversity. In addition, values of richness, equity and diversity indices (e.g. the Shannon index) have been shown to increase in relation to soilscape evolution, as observed in many ecological successions (Saldaña and Ibáñez 2004).

Ecologists have made use of these abundance distribution models according to very specific assumptions on underlying biological mechanisms (Magurran 1988). Obviously these must be different from the pedological ones given that the genesis of soil types or pedotaxa and distributions is mainly determined by both biological and non-biological factors. We know that in statistical analyses uncertainty plays a role and that more than one model can fit a given dataset. It is therefore possible to develop new abundance distribution models that could explain any resource partitioning model or to find that there are several potential resources partitioning hypotheses that could explain the fit of a dataset to a given abundance distribution model. In fact, with the exception of the broken stick model, all the statistical distribution plots mentioned above are generally ubiquitous as has been revealed in several disciplines (e.g. Korvin 1992). If soil types and soil organisms could have exactly the same distribution type based on different factors, what then is the value of species distribution models (i.e. the explanatory power of resource partitioning)? And how should this problem be solved? Even taking into account the possibility that some patterns could be the result of statistical analysis artefacts, there are too many similarities to consider all of them analytical artefacts.

There is an alternative: in the framework of the non-linear systems and sciences of the complexity it is possible to detect families of systems that show the same structure and dynamics. These disciplines regard systems as open to flows of energy and matter. It is possible that several natural resources could conform to a given family of systems. The nine patterns previously quoted are idiosyncratic of soils and biological assemblages, among others. In fact, fractals and multifractals (scale-invariant properties in space and time) are the extensions of complex (non-linear) systems, and these structures appear in both biodiversity and pedodiversity (Caniego et al. 2006). The relationships between pedodiversity, biodiversity, lithodiversity and landform diversity, from the perspective of the non-linear systems was already suggested by Ibáñez et al. (1990) and Phillips (1999) but more details can be found in Ibáñez and Bockheim (2013). This application of non-linear systems to natural resources is worthy of further consideration. Perhaps it could broaden our knowledge of natural systems in order to build a unified theory of the diversities of all the natural resources that constitute the land surface systems.

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