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Original Articles

Integrating geo-biodiversity features in the analysis of landscape patterns

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A B S T R A C T

Spatial patterns are deeply linked to ecological processes and this relationship lies at the core of landscape ecology. In turn, landscape patterns are influenced by physical, biological and anthropogenic factors. The aim of this study was to explore how specific physical and biological factors, namely geo- and biodiversity features influence landscape patterns. The focus was on microscale relationships and we chose as our focus area a small scale study site covering 3091 ha characterized by vegetation mosaics with multiple patterns. We considered geology, soil and altitude (for geodiversity) and land cover classes (for biodiversity) as superposed layers and we aggregated their elements into a new combined mosaic. Several landscape metrics related to patterns such as landscape fragmentation, connectivity of habitats and ecotone properties were computed at the class level for the new mosaic and were used in multivariate statistical analyses. We determined the most important parameters by Principal Component Analysis. The first component was mainly linked to metrics related to size variability, while the second one was related to border complexity. In the reduced space, we delineated three clusters of objects that were characterized by different landscape patterns. We analyzed the underlying geology, soil structure and occurring land cover classes for each cluster. We then performed Redundancy Analysis using geo- and biodiversity features as predictor variables and metrics as response variables. While the land cover acted as explanatory variable for the first principal axis of variation, the geodiversity features (geology and soil) were related to the second one. Specifically, the occurrence of limestone yields more complex borders of patches; some phenomena are visible *in situ*, such as limestone appearing at the surface as outcrops (lapis) that induce irregular shapes of the patches. Overall, the analyses hinted that, besides the land cover class, the underlying geology plays an important role in defining landscape patterns, and this relationship can be revealed through the use of appropriate statistical tools. On the other hand, the study area is an agro-silvopastoral landscape, where local traditional management practices are also an important driver for the occurrence of specific patterns. Therefore, understanding the links between geo- and biodiversity characteristics and landscape features can contribute to developing appropriate management and planning strategies.

1. Introduction

Landscape patterns are produced by multiple relationships between physical, biological and anthropogenic factors (Turner, 1989). Vegetation mosaics characterized by gradual transitions from grassland to forest develop in the lower altitudes of mountainous areas world-wide. Their value is not only ecologic, as biodiversity hotspots (Sebek et al., 2016), but also economic and cultural (Garrido et al., 2017). They can lead to the development of specific cultural landscapes – a cultural landscape being generally regarded as geographic area, including its natural and cultural resources (Riesenweber, 2008). Cultural landscapes were shaped by the interferences between humankind and its

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natural environment (UNESCO, 2016) and an increasing attention is paid to maintaining the equilibrium between these two defining terms. This is shown by many conservation documents, strategies and initiatives, varying from global agreements such as The World Heritage Convention (UNESCO, 2016), to international networks such as the Permanent European Conference for the Study of the Rural Landscape (Plieninger et al., 2006) or to approaches focusing on a specific landscape such as the Satoyama initiative (Takeuchi, 2010). For these reasons, it is important to deepen our knowledge on their resilience, that is to understand the capacity of the underlying ecosystems to cope with disturbances while maintaining the essentially the same structure and functions (Plieninger and Bieling, 2013; Walker et al., 2006). For instance, it is not fully clear to date how the before-mentioned factors drive the occurrence of various patterns from semi-open woodlands to complete forest regeneration or why areas remain open lands (Blackburn et al., 2014; Garbarino and Bergmeier, 2014; Wallentin et al., 2008). Besides the general rules governing the relationship between patterns and processes, several particularities need to be taken into account when dealing with such mosaics. There is a subtle interplay between the underlying physical factors and the biological characteristics, which leads to a specific ecosystem development (Bokdam and Gleichman, 2000). Furthermore, detailed elements related to both categories might be relevant in occurrence of certain patterns (e.g., Díaz et al., 1996; Smit et al., 2005, 2008).

An important category of physical factors is geodiversity features (e.g., Gray, 2005, 2008; Gray et al., 2013; Ruban, 2010). Geological diversity is determined by the parent rock and its physicochemical properties (English Nature, 2004; Gray, 2004; Kozlowski, 2004; Serrano and Ruiz-Flano, 2007). Geomorphological diversity considers additionally topographical aspects and the underlying physicochemical processes, such as weathering, that shape the land form (e.g., Alexandrowicz and Margielewski, 2010; Hjort and Luoto, 2010). Biodiversity addresses aspects as species richness and diversity, but also horizontal and vertical structure of ecosystems and landscapes (e.g., CBD, 1992; Gaston and Spicer, 2004; Serrano and Ruiz-Flano, 2007). Taking into account that both, geo- and biodiversity, refer to features of the landscape and that recently the concept of geodiversity was directly linked to spatial biodiversity patterns (Parks and Mulligan, 2010), we will use throughout the paper the term *geo-biodiversity*. Geo-biodiversity can be used as a predictor for landscape scale processes or for the occurrence of particular ecosystems. Thus, terrain parameters such as elevation, slope or topographic wetness index were used for explaining changes in landscape configuration (Peppler-Lisbach, 2003). The abundance of forest areas can be related with topographical, geological and soil factors (Acosta et al., 2005) but also soil characteristics can help to explain their distribution patterns (Coudun et al., 2006; John et al., 2007). Subsequently, a pattern of niches with different microclimatic, hydrological and nutritional properties is created that can prescribe vegetation successional patterns (Peringer and Rosenthal, 2011). On the other hand, terrain morphology and soil properties drove management decisions in woodlands that result nowadays in high forests, coppices or wood-pastures (Szabo and Hedl, 2013). Consequently, a sophisticated understanding of interferences between geodiversity and biodiversity can contribute to sustainably manage and develop landscapes (Hjort et al., 2012).

For characterizing pattern, landscape is defined as a mosaic of patches interacting with each other at different scales (e.g., Forman and Godron, 1986; Turner, 1989). The patch-corridor model (Forman, 1995) can still be considered as the most popular model for conceptualizing and representing landscape pattern as the basis for subsequent assessments by landscape metrics (e.g., Frank et al., 2012; Lausch et al., 2015; Uuemaa et al., 2013). Landscape metrics (LMs in the sequel) are used in a wide range of study areas, such as forest ecology (Innes and Koch, 1998; Pătru-Stupariu et al., 2013) and landscape studies (Botequilha Leitão and Ahern, 2002; van Eetvelde and Antrop, 2004). Also, they can be implemented for assessing a multitude of topics (Uuemaa et al., 2009), in which landscape aesthetics and biodiversity are still the most important and best-researched application area (Frank et al., 2013). Nowadays, LMs are increasingly used in mapping and assessments of ecosystem services (e.g., Andrew et al., 2014; Syrbe and Walz, 2012) and for building bridges to landscape planning (Estoque and Murayama, 2013; Frank et al., 2012; Ng et al., 2013).

Woody pastures are examples of vegetation mosaics with multiple patterns, characterized by the occurrence of woody vegetation in an open landscape (Hartel and Plieninger, 2014; Peringer et al., 2013). In the Carpathian basin, they are a predominant land use type, driven by traditional management and grazing practices (Hartel et al., 2013) or by abandonment of land (Plieninger et al., 2015; Varga and Bölöni, 2009). The characteristics of woody pastures are conditioned by the pattern of topographical factors such as rock outcrops that provide germination niches for tree seedlings (Smit et al., 2005) and soil properties related to the productivity of the grasslands (Critchley et al., 2002). They represent ‘archetypes of High Nature Value Farmlands in Europe’ (Garbarino and Bergmeier, 2014; Plieninger et al., 2015). Besides their importance for biodiversity, woody pastures are also part of the cultural heritage (Jørgensen and Quelch, 2014) and have a high socio-economic value (Bergmeier et al., 2010), since they are a traditional land use type with a long history of traditional practices. Traditional low-intensity land use, such as grazing and haying, forest management and natural disturbance regimes further diversify the structure of vegetation types into semi-open landscape mosaics that are characterized by vegetation gradients, i.e. gradual transitions from grassland to forest (Maurer et al., 2006; Plieninger et al., 2006).

With the presented study, we intended to deepen the understanding of how geo-biodiversity features determine the landscape pattern at microscale, in woody pastures in the Romanian Carpathians. The main hypothesis was that this interdependence is well reflected by numerical descriptors such as LMs. Therefore, the objective of this paper is twofold: (i) to test if a set of LMs related to connectivity, fragmentation and ecotone properties is a reliable tool to assess the particular geo-biodiversity pattern of woody pastures and to select the most representative LMs, by applying multivariate statistical analyses; (ii) to analyse to what extent geology, soil, topography and vegetation attributes influence and explain the variability of woody pasture landscape patterns, as quantified by these LMs.

2. Materials and methods

2.1. Study area

The study site (Fig. 1) is located in the Southern Romanian Carpathians, where pasture-woodlands are still a widespread land cover class and where one can find a rich mosaic of bedrocks such as limestone, marl and conglomerates. The study site is situated in the Bran-Rucăr passageway and covers a surface of 3091 ha. The altitude varies between 1100 m and 1400 m. The vegetation cover is a mixture of ungrazed beech forest (*Fagus sylvatica*) and woody pastures where Norway spruce (*Picea abies*) is the dominant tree species and juniper (*Juniperus communis*) the dominant shrub. The grasslands are composed of various communities dominated by *Agrostis capillaris* (*Agrostis tenuis*) or *Festuca rubra* (Maruşca et al., 2014). The selection of the study site was based on a preliminary field survey which provided data on micro-topographical elements such as limestone outcrops and management information.

2.2. Data sets

The database included geographical and ecological information from (a) land cover maps, (b) soil maps, (c) topographic maps, and (d) geological maps.

(a) The land cover maps were derived from orthophotomaps (scale