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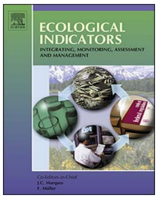

Research paper

Landscape heterogeneity as a surrogate of biodiversity in mountain systems: What is the most appropriate spatial analytical unit?

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ABSTRACT

The estimated potential of landscape metrics as a surrogate for biodiversity is strongly dependent on the spatial analytical unit used for evaluation. We assessed the relationship between terrestrial vertebrate species richness (total and taxonomic) and structural landscape heterogeneity, testing the impact of using different spatial analytical units in three mountain systems in Spain. Landscape heterogeneity was quantified through an additive partitioning of the Shannon diversity index of landscape classes. Both landscape heterogeneity and species richness were calculated using two spatial analytical unit approaches: eco-geographic *vs.* arbitrary (i.e., watersheds *vs.* square windows of different sizes 20 × 20 km, 50 × 50 km, 100 × 100 km). We predicted species richness on the basis of landscape heterogeneity by fitting separate linear models for each spatial analytical unit approach. The main results obtained showed that landscape heterogeneity influenced terrestrial vertebrate species richness. However, the emerging relationships were dependent on the spatial analytical unit approach. The eco-geographic approach showed significant relationships between landscape heterogeneity and total and taxonomic species richness in almost all cases (except mammals). Considering the arbitrary approach, landscape heterogeneity appeared as a predictor of species richness only for mammals and breeding birds and at the coarsest spatial scales. Our results claim for further consideration of eco-geographical spatial analytical unit approaches in biodiversity studies and show that the methods of this study offer a valuable cost-effective framework for biodiversity management and spatial modeling, with potential to be adapted to national and global applications.

1. Introduction

Loss of biodiversity is one of the main impacts of land use change, and is associated with landscape fragmentation and habitat loss over recent decades (Lindenmayer et al., 2002; Herrando et al., 2014). Knowledge of the factors driving biodiversity patterns has become a priority for researchers and conservation practitioners (Morelli et al., 2013). Considerable efforts have been made to develop and improve methods for evaluating components of current biodiversity to enable the identification of priorities for conservation (Priego-Santander et al., 2013). Conservation strategies require the quantification of biodiversity, although time and cost limitations of biodiversity data collection make this a challenging task (Ewers et al., 2005). Thus, the development of biodiversity indicators that reduce the effort of biodiversity estimation, therefore speeding up the decision-making process, has become a priority for conservation biologists (Rossi and van Halder 2010; Laurila-Pant et al., 2015).

There is a large body of literature in which different environmental variables (e.g., climate, land cover (Kivinen et al., 2007; Mehr et al., 2011), topography (Krömer et al., 2013; Yu et al., 2015), soil properties (Medinski et al., 2010), human population density or habitat diversity (Moreno-Rueda and Pizarro, 2007) have been used to make spatial predictions of species richness. Currently, there is increasing agreement about the consideration of landscape as the most pertinent level for biodiversity management actions (Walz, 2011), since landscape-based evaluations provide a larger-scale perspective of ecological processes than traditional site-based ones (Pino et al., 2000). The use of landscape metrics as a proxy of species richness has become a popular approach (Lindenmayer et al., 2002; Rossi and van Halder, 2010), made easier by the continuous development of remote sensing techniques and Geographic Information Systems (GIS) (Wagner and Fortin,1987). Amongst the large number of landscape metrics used as biodiversity surrogates, landscape heterogeneity is gaining valuable recognition within conservation strategies (Walz, 2011). It is generally accepted that landscape heterogeneity is positively related to ecological niche diversity (Katayama et al., 2014). Furthermore, landscape heterogeneity plays an

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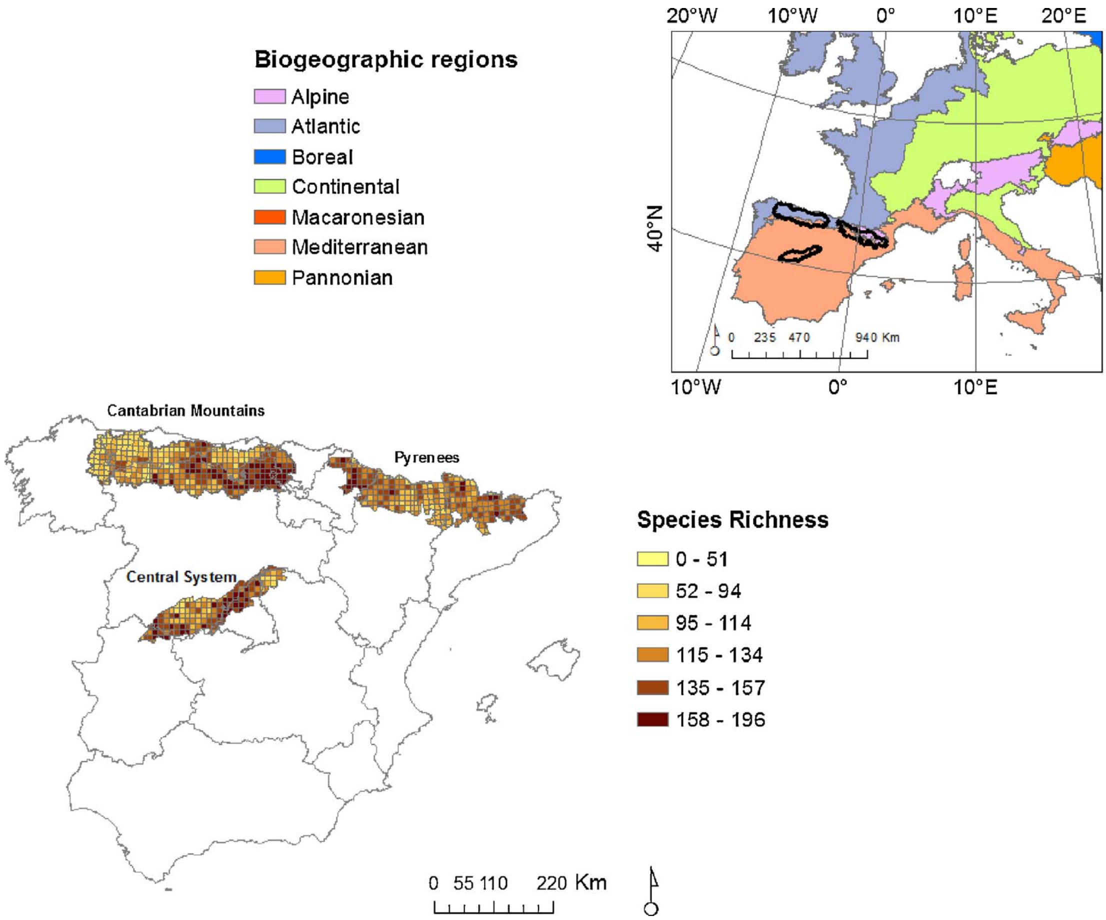

Fig. 1. Study area: The Cantabrian Mountains, the Central System and the Spanish Pyrenees.
Information on biogeographic regions was obtained from the Spanish Ministry of Agriculture, Food and Environment (http://www.magrama.gob.es/).

important role in population dynamics, as it may control dispersal rates, movement patterns or foraging strategies (Johnson et al., 1992), which suggests some connection between landscape heterogeneity and species richness. Nevertheless, the estimation of biodiversity from landscape metrics is often affected by the methods employed to observe, analyse and process landscape patterns (Walz, 2011). Since landscape metrics, including landscape heterogeneity, describe geometric and spatial properties of landscape (Gimona et al., 2009), the ecological response emerging from landscape analyses might be conditioned by the shape (i.e., delineated boundaries; Moser et al., 2007; Cushman and McGarigal, 2008) or size (i.e., spatial scale) of the analytical unit used for landscape quantification (Weibull et al., 2000; Plexida et al., 2014; Ye et al., 2015).

The landscape is a continuum, but for practical reasons it must be split into spatial analytical units providing a frame for landscape metrics quantification. This is often rather arbitrary (Verberk et al., 2006; Walz, 2011). Difficulties arise as differently delineated spatial analytical units might provide different statistical relationships for the same ecological process, making the interpretation and applicability of landscape metrics estimations challenging (Saura and Martínez-Millán, 2001). Most studies addressing landscape heterogeneity as a surrogate of species richness (e.g. Atauri and de Lucio, 2001; Moreno-Rueda and Pizarro, 2007; Schindler et al., 2013) are based on a systematic partition of the landscape using arbitrarily defined spatial analytical units, such as UTM grids or circular buffers. However, the use of spatial analytical units with eco-geographic meaning could also provide a useful approach when predicting biodiversity, as displayed by Priego-Santander et al. (2013). This study showed the potential of landscape heterogeneity as a predictor of plant richness on the basis of land units defined from geomorphology, geology, relief, climate, soil and land cover features. Watersheds are increasingly being used in environmental modelling and management, as they represent integrated socio-ecological (Mayer et al., 2014), geomorphological (Montgomery et al., 1995) and multifunctional (Karadağ, 2013) units with potential application for analyses at multiple scales (Tinker et al., 1998). For example, watersheds have been considered as operational spatial units to assess the relationship between soil erosion and regional landscape change (Li and Zhou, 2015), to identify and manage natural resources (Baloch and Tanik, 2008) and to analyse land cover change (Mendoza et al., 2011; Álvarez-Martínez et al., 2014). However, the application of eco-geographical units, including watersheds, as spatial analytical units in biodiversity modelling is under-evaluated. There is a clear need to explore the role of eco-geographical spatial analytical unit approaches as an alternative to traditional arbitrary ones in biodiversity studies.

Similarly, the influence of the size of the spatial analytical unit on the detection of relationships between landscape heterogeneity and species richness has been highlighted in different studies (e.g. Tews et al., 2004; Morelli et al., 2013; Schindler et al., 2013). Relationships emerging from the use of a particular spatial analytical-unit size are not necessarily consistent across different sizes. This is a consequence of the operational scale at which organisms interact with their environment (Tews et al., 2004). Taxa with a higher mobility and a strong demand for space are expected to be more influenced by larger landscape surface areas than smaller or sedentary species (Suárez-Seoane and Baudry, 2002; Schindler et al., 2013). Thus, multiscale analyses are required to detect the scale at which ecological phenomena leave their biological signal (Lechner et al., 2012).

In comparison with other systems, the higher environmental