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Research article

A procedure of landscape services assessment based on mosaics of patches and boundaries

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A B S T R A C T

We develop a procedure for assessing the environmental value of landscape mosaics that simultaneously considers the values of land use patches and the values of the boundaries between them. These boundaries indicate the ecological interactions between the patches. A landscape mosaic is defined as a set of patches and the boundaries between them and corresponds to a spatial pattern of ecological interactions. The procedure is performed in two steps: (*i*) an environmental assessment of land use patches by means of a function that integrates values based on the goods and services the patches provide, and (*ii*) an environmental valuation of mosaics using a function that integrates the environmental values of their patches and the types and frequencies of the boundaries between them. This procedure allows us to measure how changes in land uses or in their spatial arrangement cause variations in the environmental value of landscape mosaics and therefore in that of the whole landscape.

The procedure was tested in the Sierra Norte of Madrid (central Spain). The results show that the environmental values of the landscape depend not only on the land use patches but also on the values associated with the pattern of the boundaries within the mosaics. The results also highlight the importance of the boundaries between land use patches as determinants of the goods and services provided by the landscape.

1. Introduction

To incorporate ecological knowledge into decision-making regarding the use of natural resources, landscape is defined as different ecosystems interacting in a particular way at a given spatial and temporal scale (Bernáldez, 1981; Forman and Godron, 1986; Zonneveld, 1995). Usually, these ecosystems are recognised as land use patches that are internally homogeneous in terms of the interactions among their components, e.g., water, soil, nutrients, plants, and animals. Commonly, environmental valuations are based on these patches and focus on the goods and services they provide to society (Costanza et al., 1997; Fisher et al., 2009; Hermann et al., 2011; McHarg, 1969; Verburg et al., 2009; Walz, 2008; Westman, 1977). In fact, the concept of ecosystem function, defined as the capacity of natural processes and components to provide goods and services that directly or indirectly satisfy human needs (De Groot, 1992), explicitly refers to patches that correspond to different ecosystems or land uses. In some cases, the term is used to describe the internal functioning of ecosystems (e.g., maintenance of energy flows, nutrient cycling, and trophic interactions), and in other cases, it is applied to the benefits that society can obtain from those ecosystem processes (e.g., food, water and air purification, recreation, and waste treatment) (De Groot, 2006). A wide range of ecosystem functions and their goods and services have been described in the literature (Bastian et al., 2006; Costanza et al., 1997, 2014; Daily et al., 2000; De Groot, 1992; De Groot et al., 2002; MEA, 2005; Meyer and Grabaum, 2008; Zube, 1989).

However, landscape patches are not isolated but rather interact with other ones. These patches are spatially arranged in a particular way; thus, the ecological processes in any landscape patch are a function of the patterns and magnitudes of the exchanges between the patch and its surroundings (Forman, 1990; Margalef, 1979; Wiens et al., 1985). Thus, boundaries play a crucial role as regulatory elements of the type, direction and magnitude of the exchanges occurring between patches (Cadenasso et al., 2003; Fortin, 1994; Fortin et al., 2000; Haber, 1990; Hansen et al., 1988; Margalef, 1979; Metzger and Muller, 1996; Peters et al., 2006; Van der Maarel, 1990; Wiens et al., 1985; Wiens, 2002). This regulatory function of

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boundaries can be observed in many ecological features, such as species survival, primary production and water and nutrient flows in the landscape (Bastian et al., 2015; Hansen and Di Castri, 1992; Hood et al., 2003; López-Barrera et al., 2007; Mander et al., 2000; Palmer et al., 2000; Seastedt et al., 2004; Turner and Chapin, 2005; Van Oost et al., 2000; Wiens, 2002; Wilcox et al., 2003). These features ultimately provide goods and services to society and contribute to the environmental value of the landscape (Termorshuizen and Opdam, 2009). Consequently, both patches and boundaries must be considered in landscape assessment, and their values should be integrated. To this end, landscape mosaics are useful. A landscape mosaic is defined as a spatial arrangement of different patches and the boundaries between them and, consequently, involves a pattern of ecological interactions (Cantwell and Forman, 1993; De Pablo et al., 2012; Forman, 1995; Roldán et al., 2003, 2006; Wiens et al., 1993). Patches differ in terms of their composition, structure and ecological maturity (Hansen et al., 1988), and their boundaries are the result of the patterns of spatial interactions between neighbouring patches (Roldán et al., 2006). Mosaics integrate information about land uses and boundaries and are therefore the best descriptors of landscape change (De Pablo et al., 2012; Roldán et al., 2006).

Several studies have demonstrated the usefulness of landscape mosaics in environmental planning and management (Bertolo et al., 2015; Forman, 1990; Hardt et al., 2013; Hersperger, 2006; Kuttner et al., 2014; Roldán et al., 2006; Simmering et al., 2006; Wiens et al., 1993), and numerous mosaic-based metrics are used to describe landscapes (De Pablo et al., 2012; Farina, 2000; Forman, 1995; Hanski, 2001; Hardt et al., 2013; Kuussaari et al., 2009; Noss, 1990; Zeng and Ben Wu, 2005). However, decision-making in environmental planning is based on the values of land use patches without regard to the interactions across their boundaries.

In this paper, we present a procedure to estimate the environmental value of landscape mosaics by integrating the values of land use patches and their boundaries. First, land use patches are assessed according to different partial values based on the environmental goods and services they provide. Then, using a multivariate analysis, these values are integrated into a unique environmental value for each land use. Finally, landscape mosaics are assessed through the integration of the environmental values of their land use patches and the types and frequencies of the boundaries between them.

2. Materials and methods

2.1. Study area

The case study area is located in the Sierra Norte of Madrid (Somosierra Mountain Range, Central System) (Fig. 1). This is a mountainous area that, since the 1940s, has undergone a decline in traditional agricultural activities and an increase in forestry plantations, mainly of pine (*Pinus sylvestris* L. and *Pinus pinaster* L.), for timber production and soil protection. Reservoirs have been built to supply water to the nearby conurbation of Madrid. This study area was selected for testing the procedure because the temporal variations in the frequencies of land uses and in the patterns of their boundaries are well known to the authors (De Pablo et al., 2012; Roldán et al., 2003, 2006). The area is also representative of the central Iberian Peninsula mountainous landscapes near a metropolitan area with a population of approximately five million.

2.2. Land use assessment

The digital database of land use maps used in this study was provided by Roldán et al. (2003, 2006). The maps are based on aerial photographs from 1946 and 1999 at a scale of 1:50,000. These maps are shown in Fig. 2. See Appendix A for the land use categories that were considered.

The environmental value of a land use depends on the goods and services it provides (McHarg, 1969; MEA, 2005; Sancho-Royo et al., 1981). In this work, we assessed the naturalistic, productive, systemic, aesthetic, recreational and cultural goods and services (Table 1).

For each land use, six partial values, *Vi*, were assigned to the above goods and services. The assessment for each partial value was conducted by ordering the uses on an ordinal scale ranging from 1 (lowest value) to *n* (maximum value) (Table 2). Zero was used when a good or service was not applicable to the land use (e.g., the productive value of the 'Housing estates' land use). The maximum value, *n*, corresponding to each good and service depends on its variability in the territory. In any valuation process, it is well known that the values of a landscape are not comparable to those of other landscapes. However, the values of a landscape at different times are comparable provided that the same criteria and the same scale are applied. In this case study, values were assigned by the authors in consensus with other experts based on their knowledge of the study area (De Pablo et al., 2012; Roldán et al., 2003, 2006) and on cost-benefit criteria widely used in landscape planning (MEA, 2005; Raimond and Brown, 2006; Ruiz-Labourdette et al., 2010; Sancho-Royo et al., 1981). In any case, values can be assigned taking into account the points of view of various specialists, stakeholders, local people and any other agents concerned with the study area. Having established the valuation criteria, shown in Table 1, the assigned values do not vary substantially despite change in agents, as the valuation criteria embrace the scientific and social consensus about the goods and services assessed.

To integrate the partial values of each land use into a unique environmental value, a matrix of land uses and partial values was generated. A principal component analysis (PCA) was performed on this matrix. PCA is a commonly used technique in this type of study for integrating the partial values objectively, because it allows us to identify the trends in the variation of the partial land use values along the ordination axes (Montalvo et al., 1993; Ramírez-Sanz et al., 2000; Ruiz-Labourdette et al., 2010). Each axis is a linear combination of the partial land use values; thus, the coordinate of each land use k on axis j is given by

$$C_{jk} = \sum_i b_{ij} z_{ik} \quad [1]$$

where C_{jk} is the coordinate of land use k on axis j; b_{ij} is the loading factor of partial value i and inform us about the relative contributions of goods and services to the environmental value, *Ve*, of each land use; z_{ik} is the standardised partial value i for land use k. In this manner, C_{jk} is the weighted sum of the partial values for use k, and it summarises the overall environmental value Ve_j of this use on axis j.

The variance, s^2, explained by the ordination axes synthesises the variability among the partial values in the set of land uses. Accounting for this variability on the different PCA axes, the environmental value, *Ve*, of each land use is calculated as follows:

$$Ve_k = \sum_j s_j^2 \left(\sum_k C_{jk} \right) = \sum_j s_j^2 \left(\sum_k \sum_i b_{ij} z_{ik} \right) \quad [2]$$

where Ve_k is the environmental value of use k, and $s^2{}_j$ is the variance explained by axis j. In this manner, the *Ve* of a land use is the combination of its partial values weighted by the variance explained by each PCA axis.