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A multiscale analysis of ecosystem services supply in the NW Iberian Peninsula from a functional perspective

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A B S T R A C T

In recent years, the assessment of ecosystem services (ES) supply has been based on the use of Land Use/Land Cover (LULC) data as proxies for spatial representation of ecosystems. Nevertheless, some shortcomings of this method, such as uncertainties derived from generalization of the ecosystem types and assumptions of invariance across spatial scales, indicate the need for new approaches. Such approaches could be aimed at improving knowledge of the relationships between ecosystem services and landscape structure and the spatial characteristics of ES patterns. In this study, we propose an integrative approach that involves the generation and analysis of continuous maps representing the supply of five ES potentially related to the amount of biomass. Five remote sensing images of the Northwestern Iberian Peninsula, obtained with Landsat-5 TM, were used to generate a proxy for net primary production by combining the normalized difference vegetation index (NDVI) of each image to calculate a ΣNDVI index that could act as a potential indicator of some ecosystem services. This information was combined with three variables – terrain slope, population density and occurrence of protected areas – to produce spatial models for the five ES and eventually a series of five supply maps. Food, materials and energy provision services showed a clustered pattern, with high supply values in flat zones and areas with high population densities. In contrast, mass flow and climate regulation services were more widely distributed throughout the study area. The five ecosystem service patterns were analyzed at different scales by two methods: lacunarity and four term local quadrat variance (4TLQV) analysis. These methods revealed differences in the spatial pattern: lacunarity analysis was useful for detection of scale thresholds at the local level, whereas 4TLQV was more sensitive to scale thresholds at larger spatial levels. Thus, the variance analysis yielded higher values for larger windows sizes, particularly for provisioning services. The results demonstrated the suitability of the proposed approach for the spatially explicit modeling of ecosystem services, avoiding the uncertainty of other assessments such as those based on LULC data, and for the exploratory analysis of ES supply from a spatial point of view.

1. Introduction

Analysis of ecosystem services (ES) has been addressed in many scientific articles and research projects during the last few decades (e.g., MEA, 2005; EME, 2011). Despite the advances made in gathering a theoretical body of information and in the analysis and classification of ES, there is still a general lack of information and standardized approaches for integrating ecosystem services analysis in land planning and management (de Groot et al., 2010; Koschke et al., 2012). There is also a need for methods of quantifying the supply and the demand of ES from a spatial perspective (Burkhard et al., 2012, 2014). Therefore, the development of methods for accurate mapping and correct quantification of ecosystem services is considered a key requirement for implementation of the ES concept in environmental policies and land use decision making (Daily and Matson, 2008).

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Assessment of ES is often based on Land Use/Land Cover (LULC) data (e.g., Frank et al., 2012; Koschke et al., 2012; Kandziora et al., 2013). This approach enables the assessment of large areas and development of multi-scale analysis. However, some common problems have been detected in this type of assessment (Eigenbrod et al., 2010a): first, the generalization over the whole study area of standard values for a given variable sampled in a location and, second, the assumption of invariance across different spatial scales. In addition, the map resolution may not be sufficient for location of some ecosystem services, particularly when such ES are associated with ecosystems that cover small areas or that are fragmented in small patches barely identified in the LULC datasets (Kandziora et al., 2013). In this respect, Hou et al. (2013) also identified a series of uncertainty sources commonly found in assessment of spatial ecosystem services. These authors highlighted the uncertainties associated with the use of LULC data, particularly missing data, scale issues or imprecise function/ecosystem service classifications or definitions.

Analysis of ES should not rely solely on identification of the relationships between the ecosystem services and a given LULC class (Frank et al., 2012), as some ES may be associated with several classes at the same time and/or depend on complex relationships between LULC classes. Different ecosystem services might show multiple spatial scales because they originate in ecological processes revealed at a wide range of spatial levels (Roces-Díaz et al., 2014), and therefore the multi-scale perspective should also be taken into account in such ES analysis (Burkhard et al., 2012). Similarly, the relationships between landscape pattern and the supply and demand of ecosystem services should also be addressed, along with improvement of the spatial representation of ES supply.

The availability of datasets with spatially explicit information obtained from sources other than extrapolation or generalization processes may prevent the above-mentioned problems identified by Eigenbrod et al. (2010a). Thus, some authors have emphasized the use of remote sensing (RS) data to overcome some of the traditional flaws of ES assessments (Ayanu et al., 2012; Burkhard et al., 2013; Cabello et al., 2012). Indeed, some recent studies analyzing ES supply from a functional perspective have used RS datasets for quantifying energy flows as a proxy for ecosystem services distribution (Petrosillo et al., 2013). In other studies, RS data have been used to characterize the territory structure and the landscape pattern and eventually to define functional types of ecosystems (Paruelo et al., 2001, 2004; Alcaraz et al., 2006; Fernandez et al., 2010); furthermore, Kandziora et al. (2014) combined RS data and the ES approach to identify the spatial and temporal dynamics of ES. Most such studies are based on the analysis of spatial heterogeneity of some parameters associated with vegetation structure (such as the normalized difference vegetation index (NDVI)) and energy distribution (such as the albedo and land surface temperature). The use of vegetation indices – such as the aforementioned NDVI – is common in several fields of environmental research. In fact, different authors have associated this index with vegetation structure and other parameters, e.g., primary production and carbon balance (Running et al., 1999; Huete et al., 2002), which are relevant in ES analysis.

Net primary production (NPP) is often assumed to be a key process in the study of the relationships between ecological functioning and ES supply (MEA, 2005) because it drives the amount of biomass in an ecosystem. NPP is defined as the balance between the carbon fixed in photosynthesis and the carbon lost by plant respiration (both due to growth and maintenance respiration) and is generally considered a type of organization of the energy essential for the maintenance of natural capital and the well-being of society (Odum, 1971; Costanza et al., 1998). For this reason, different ES assessments (i.e., Richmond et al., 2007; Petrosillo et al., 2013) established the NPP as a proxy for quantifying different ecosystem services, such as provision of food and timber. Thus, the combination of different methods of ES analysis, such as those based on LULC data with RS information, may be useful for reducing some of the typical errors that appear in assessment of the ecosystem services.

Taking all the above into account, we propose a method for the analysis of five key ecosystem services from a functional perspective. For comparison of the five ES models obtained from a spatial point of view, we applied two methods of spatial analysis that depend on the scale. First, we used lacunarity (Mandelbrot, 1983; Plotnick et al., 1993; Fortin and Dale, 2005), which analyzes the regularity of the pattern of the gaps (in our case they are the no supply zones), and second, we used the four term local quadrat variance (4TLQV; Dale, 1999; Fortin and Dale, 2005), which analyzes the increase in variance with increasing scale of analysis. More precisely, the objectives of this study were as follows: (i) to estimate the supply of five ecosystem services associated with biomass production, by using remote sensing data and spatially explicit models; and (ii) to analyze the differences between these models by establishing the characteristic spatial scale of each ES pattern.

2. Material and methods

2.1. Study area

The study area (which covers an area of 2134 km^2) is located in the northwest of the Iberian Peninsula (Fig. 1) and is included in the European Atlantic Biogeographic Region (EEA, 2013). The climate of the area is defined as oceanic, with average annual rainfall values higher than 1000 l/m^2 and with no summer drought (Ninyerola et al., 2005). The area is mountainous, with an elevation ranging from sea level to 2000 m (Fig. 1). The mean slope is steeper than 40% and only 5% of the area has a slope lower than 10%.

The landscape of the area has been subject to strong anthropogenic influence and a general decline in woodland surface during the last two thousand years in relation to the increase in agricultural and livestock use (Muñoz-Sobrino et al., 2005). The areas with the most fertile and deepest soils are often used for agricultural crop production and dairy farms. These uses are mixed with scattered patches of woodland of native species (*Quercus robur* L. and *Castanea sativa* Mill.) and forest plantations for timber production (*Eucalyptus globulus* Labill., *Pinus pinaster* Ait. and *Pinus radiata* D. Don). In the highlands, the slope aspect plays a key role in the distribution of vegetation, and shady slopes are usually covered by forest comprising *Q. robur*, *Quercus petraea* (Matt.) Liebl., *Fagus sylvatica* L. or *Betula pubescens* Ehrh., while scrubland is more common on south-facing slopes. The anthropogenic influence is also associated with the occurrence of scrub communities (mainly heath, gorse and broom) at a wide range of elevations (Diaz and Fernández-Prieto, 1994).

2.2. Data collection and pre-processing

The different stages of data collection, pre-processing and data analysis are summarized in Fig. 2. Remote sensing analysis was based on imagery from the Thematic Mapper (TM) sensor of Landsat-5 satellite. These images have an original spatial resolution of 30 m and provide information about six spectral bands in the visible electromagnetic spectrum (blue, green and red channels: 1, 2 and 3, respectively), near infrared (channel 4), short wavelength infrared (channels 5 and 7) and thermal infrared (channel 6).

We selected a time series of images with low cloud coverage spanning a recent phenological year (covering all four seasons). The first image selected corresponds to autumn (2010/10/18), the