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Assessing the distribution of forest ecosystem services in a highly populated Mediterranean region

Jose V. Roces-Díaz[a,b,*], Jordi Vayreda[a], Mireia Banqué-Casanovas[a], Martí Cusó[a], Marc Anton[c], José A. Bonet[d,e], Lluís Brotons[a,d,f], Miquel De Cáceres[a,d], Sergi Herrando[a,c], Juan Martínez de Aragón[d], Sergio de-Miguel[e], Jordi Martínez-Vilalta[a,g]

[a] CREAF, E08193 Bellaterra (Cerdanyola del Vallès), Catalonia, Spain
[b] Department of Geography, Swansea University, Singleton Park, Swansea SA2 8PP, United Kingdom
[c] Catalan Ornithological Institute, Natural History Museum of Barcelona, 08019 Barcelona, Catalonia, Spain
[d] Forest Sciences Centre of Catalonia (CEMFOR-CTFC), 25280 Solsona, Catalonia, Spain
[e] Department of Crop and Forest Sciences, Universitat de Lleida-Agrotecnio Center (UdL-Agrotecnio), Av. Rovira Roure, 191, E-25198 Lleida, Catalonia, Spain
[f] Consejo Superior de Investigaciones Científicas (CSIC), 08193 Cerdanyola del Valles, Catalonia, Spain
[g] Universitat Autònoma de Barcelona, E08193 Bellaterra (Cerdanyola del Vallès), Catalonia, Spain

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ABSTRACT

Forest ecosystems provide a wide range of goods and services to society and host high levels of biodiversity. Nevertheless, forest ecosystem services (ES) are often quantified and assessed using simplified methodologies (e.g., proxy methods based exclusively on Land Use Land Cover maps) that introduce substantial uncertainty in the analysis by ignoring, for instance, the species composition and spatial configuration of the ecosystems studied. In this work we defined and calculated a set of 12 indicators of several ES for the forests of the highly populated region of Catalonia (North-eastern Iberian Peninsula). The indicators combined different sources of information such as forest surveys, ecological model predictions and official statistics, but also included additional land cover information. All ES indicators were aggregated at the municipality level to compare their values and distribution patterns. We assessed spatial trade-offs and synergies among ES, as well as their relationships with a set of socioeconomic, climatic and biodiversity variables using correlation analyses and mixed-effects models. The results suggest a clustering of provisioning and regulating ES in mountainous zones towards the North of the study area. These two types of services showed a high degree of spatial similarity and presented high positive correlations. In contrast, cultural ES showed a more scattered pattern, which included lower elevation areas in the South of the study region. Climatic conditions were the main determinants of the spatial variability in the supply of the different ES, with most indicators being positively associated with precipitation and negatively associated with temperature. In addition, biodiversity (particularly woody species richness) showed positive relations with most of these ES, while socioeconomic variables (such as population density and the percentage employment in agriculture) showed negative associations with most of them. The combination of information from different data sources (including primary data) allowed for a detailed analysis of forest ES, likely removing some of the problems derived from approaches based only on proxy methods. In addition, the use of municipalities as study unit makes results directly relevant to management and planning strategies operating at this scale (e.g., forest management and planning).

1. Introduction

Forest ecosystems are key elements for the maintenance of global biodiversity (Brooks et al., 2006). They support a range of ecosystem functions and provide multiple and essential ecosystem services (ES) to society (MEA, 2005). Some of the main forest ES can be classified as regulating services: climate and water regulation, erosion and flood control, etc. (Miura et al., 2015). However, materials and energy provision and cultural services are also relevant in forests (MEA, 2005). Forest ecosystems have been strongly disturbed and modified by the human use of the landscapes, although the intensity of historical disturbances and the current condition of these ecosystems are highly heterogeneous in space (FAO, 2014; Trumbore et al., 2015).

Several authors have highlighted the relevance of the biodiversity

* Corresponding author at: CREAF, Autonomous University of Barcelona, E-08193 Cerdanyola del Vallès, Barcelona, Spain.
E-mail addresses: jvroces@gmail.com, j.v.roces@swansea.ac.uk (J.V. Roces-Díaz).

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contained in Mediterranean landscapes (Brooks et al., 2006) and in particular in the Mediterranean Basin (Medail and Quezel, 1999; Hampe and Petit, 2005), which is considered a biodiversity hotspot of global relevance (Myers et al., 2000). The forests of this region have been managed and modified for millennia due to the historical use of natural resources by human societies (Underwood et al., 2009). In the context of global change, the development of effective management and conservation strategies is key for the maintenance of their diversity and ecosystem functions (Costanza et al., 1997). A series of drivers have been identified as having potential effects on forest ecosystems and their supply of ES (EME, 2011; Thom and Seidl, 2016), including land-use changes, wildfires, climate change, alien species, pests and pathogens (Vila et al., 2010; Doblas-Miranda et al., 2015).

Methodological factors may have a large impact on the quantification of ES (Eigenbrod et al., 2010; Van der Biest et al., 2015) and are important sources of uncertainty in ES assessments (Hou et al., 2013). Land Use/Land Cover (LULC) information often constitutes the basis for ES assessments (Hou et al., 2013). However, the use of proxy-based methods relying only on LULC data assumes that if one class (an ecosystem type) provides a specific ES, the level of supply is constant in space, neglecting the importance of other ES drivers not represented by land use categories. This leads to a potentially large generalization error in ES assessments (Plummer, 2009). Notably, these proxy-based approaches often hide large differences in the composition and structure of the forests that drive ecosystem functioning (Vila et al., 2007; Ruiz-Benito et al., 2014) and ES supply (Alamgir et al., 2016; Sutherland et al., 2016). Recent studies overcome some of the limitations of proxy-based methods by defining specific bio-physical indicators (Rodríguez-Loinaz et al., 2015) or by using specific information about the structure and the composition of these ecosystems (Roces-Díaz et al., 2017). Finally, accurate assessments of ES should include the analysis of ES spatial patterns and their spatial associations (Andrew et al., 2015), including synergies and trade-offs as well the identification of areas with particularly high levels of overall supply (hotspots; Mouchet et al., 2014; Schröter and Remme, 2016).

Forest planning and management strategies are beginning to include forest ES as key elements in their assessments (e.g. Frank et al., 2015; Triviño et al., 2015), which can help to visualize and promote the multifunctionality of these systems. Spatial-dependent aspects, such as the scale and the administrative level of analysis, become particularly relevant for planning and management objectives (Hein et al., 2006). In this regard, the municipal domain often offers a good compromise between reasonable spatial resolution and administrative relevance (Rodríguez-Loinaz et al., 2015; Roces-Díaz et al., 2018). Within this management-oriented perspective, the spatial patterns and relationships between ES (trade-offs and synergies) should also be evaluated (Duncker et al., 2012). For instance, negative relationships are frequently reported among materials provision (such as timber) and cultural services (García-Nieto et al., 2013) or biodiversity (Duncker et al., 2012).

In recent years several studies have analysed the ES provided by European Mediterranean landscapes and uncovered their strong relations with social and environmental characteristics (Garcia-Llorente et al., 2015). Some of these studies have focused on the assessment of specific, particularly relevant ES such as water provision (Quintas-Soriano et al., 2014) or erosion regulation (Guerra et al., 2016), while other works have described and analyzed all the ES provided by specific types of forest ecosystems (e.g., cork oak woodlands (Bugalho et al., 2011)). However, there are still few studies addressing different forest types at the regional scale and including a complete set of ES as a necessary step to address trade-offs and spatial variability in their overall provision (but see García-Nieto et al., 2013).

In this work we define a comprehensive set of bio-physical indicators of forest ES for Catalonia (North-eastern Spain) on the basis of different data sources, and assess them at the municipality level. The specific objectives of this work are: i) to analyze the spatial patterns of these ES and to identify their main hotspot areas; and ii) to assess the spatial relationships of these ES (trade-offs and synergies) and the association between these ES and different socioeconomic, climatic and biodiversity variables that characterize the study area. We hypothesize that the ES analyzed will show clearly differentiated spatial patterns, with a high clustering of provision and regulating services on mountainous municipalities with higher forest cover and lower population density. Other ES (e.g., cultural) will be associated to more populated areas. These disjoint spatial patterns may reflect trade-offs between different ES.

2. Material and methods

2.1. Study area and outline of the experimental approach

Our study area is Catalonia (North-eastern Spain; Fig. 1), an administrative region that covers 32,114 km^2. It is mainly located in the Mediterranean Biogeographic Region, although a part of its northern area (the Pyrenees Mountains) belongs to the Alpine Region. It is a mountainous area with an altitudinal range from the sea level to more than 3000 m on the highest peaks of the Pyrenees. Catalonia had a population of 7,504,008 people in 2015, 43% of them concentrated in the metropolitan area around the capital city (Barcelona, 636 km^2). It is a highly forested region (43% of its area was covered by forest; LCMC, 2009) where about 33% of the land area was included in the Natura 2000 Network (a system of nature protection areas in the territory of the European Union). It is dominated by tree species of the Pinaceae and Fagaceae families. Forests from coastal and low altitude areas are dominated by *Pinus halepensis* Mill. (Aleppo pine), *Quercus faginea* Lam. (Portuguese oak) and *Quercus ilex* L. (Holm oak). At middle-altitude ranges (from 800 to 1500 m) the main species are *Pinus sylvestris* L. (Scots pine), *Pinus nigra* J.F. Arnold (Black pine), *Quercus pubescens* Willd. (Downy oak, synonym of *Quercus humilis* Mill.) and also *Fagus sylvatica* L. (European beech) in the wettest zones. Finally, at altitudes higher than 1500 m the main species are *Pinus uncinata* Raymond ex A.DC. (Mountain pine) and *Abies alba* Mill. (Silver fir). These forests have shown expansion and shrinkage processes over the last millennia in congruence with changes in the environmental conditions on the Mediterranean Basin and historic land use (Grove and Rackham, 2003). Importantly, recent episodes of forest decline have been detected in the study area, affecting mostly species reaching the southern limit of their distribution in the Iberian peninsula, such as *P. sylvestris* (e.g., Martínez-Vilalta and Piñol, 2002) and *F. sylvatica* (e.g., Peñuelas and Boada, 2003). Approximately 80% of the forests in Catalonia are privately-owned, whereas the remaining 20% are public.

The spatial unit of our analysis was the municipality (N = 947 municipalities in Catalonia). ES maps were obtained at this municipality level (see below), where values from different sources (including raster format) were aggregated to polygons. As we focused on forest ecosystems and on ES capacity or actual supply (not demand), we restricted our analyses to those municipalities with substantial forest cover. Thus, we selected only those municipalities that contained at least three permanent plots of the Third National Forest Inventory of Spain (NFI; MAGRAMA, 1997–2007), which was considered a minimum sample size to obtain representative estimates and perform statistical comparisons. The Spanish NFI is an intensive program of periodic surveys (every ~10 years) that cover the whole forested area of Spain following a uniform sampling design (Appendix S1). Data of the 3rd NFI, conducted in Catalonia in 2000–2001, is used unless otherwise stated. NFI plot density is ~1 plot/km^2 of forest, so that the 3 plot threshold corresponds with an average of (at least) 300 ha of forest per municipality, resulting in a subset of 576 municipalities. Forest cover ranged between 10% and 95% in these municipalities.

In addition to using NFI data to delineate the areas (municipalities) of interest to this study, we also used the NFI dataset as a basis for the assessment of most ES. The majority of ES indicators were calculated