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The spatial level of analysis affects the patterns of forest ecosystem services supply and their relationships

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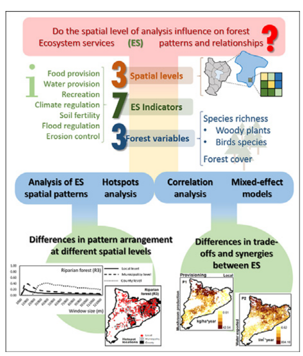
HIGHLIGHTS

- Scale is a relevant aspect in the analysis and of Ecosystem Services (ES).
- The effects of the spatial level of analysis on 7 ES indicators were assessed.
- ES Indicators were estimated at local (1 km^2), municipality and county levels.
- Averaging effects at higher spatial levels obscured local ES heterogeneity patterns.
- Identification of hotspots and ES relationships depend on the level of analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

The implementation of the Ecosystem Services (ES) framework (including supply and demand) should be based on accurate spatial assessments to make it useful for land planning or environmental management. Despite the inherent dependence of ES assessments on the spatial resolution at which they are conducted, the studies analyzing these effects on ES supply and their relationships are still scarce. To study the influence of the spatial level of analysis on ES patterns and on the relationships among different ES, we selected seven indicators representing ES supply and three variables that describe forest cover and biodiversity for Catalonia (NE Iberian Peninsula). These indicators were estimated at three different scales: local, municipality and county. Our results showed differences in the ES patterns among the levels of analysis. The higher levels (municipality/county) removed part of the local heterogeneity of the patterns observed at the local scale, particularly for ES indicators characterized by a finely grained, scattered distribution. The relationships between ES indicators were generally similar at the three levels. However, some negative relationships (potential trade-offs) that were detected at the local level changed to positive (and significant) relationships at municipality and county. Spatial autocorrelation showed similarities between patterns at local and municipality levels, but differences with county level. We conclude that the use of high-resolution spatial data is preferable whenever available, in particular when identifying

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hotspots or trade-offs/synergies is of primary interest. When the main objective is describing broad patterns of ES, intermediate levels (e.g., municipality) are also adequate, as they conserve many of the properties of assessments conducted at finer scales, allowing the integration of data sources and, usually, being more directly relevant for policy-making. In conclusion, our results warn against the uncritical use of coarse (aggregated) spatial ES data and indicators in strategies for land use planning and forest conservation.

1. Introduction

Ecosystem services (ES) can be defined as those benefits provided directly and indirectly by the ecological functioning of nature, and they are key for the wellbeing of human societies (MEA, 2005). This concept bridges science-based and societal considerations and has been growing in relevance since the 1990s. Thus, different international initiatives appeared in the last 20 years focused on their assessment (i.e. MEA, 2005; TEEB, 2010; IPBES, 2012), together with a growing scientific interest (Seppelt et al., 2011; Boerema et al., 2016). Different authors have highlighted the potential applications of the ES concept for sustainable land use planning (Daily et al., 2009; Baró et al., 2016), natural resources management (Tallis and Polasky, 2009) or biodiversity conservation (Chan et al., 2011). At the same time, there is a need to develop integrative frameworks for ES assessment (Kremen, 2005; de Groot et al., 2010) including biodiversity, bio-physical and social aspects of the environment, and also covering as much as possible the different components of ES (cascade approach including supply, demand and flow) (Potschin and Haines-Young, 2011; Yahdjian et al., 2015).

The implementation of environmental management based on ES needs to be based on spatial approaches (Egoh et al., 2008; Andrew et al., 2015) that involve mapping and characterizing both ES supply and demand (Burkhard et al., 2012). Consistent with this, most ES assessments (and ES-based studies) performed in recent years have included a spatially explicit perspective (Seppelt et al., 2011). However, different authors have pointed out the need to account for spatial patterns in more rigorous ways (Boerema et al., 2016) and to reduce the uncertainty associated with ES mapping methods (Hou et al., 2013). The effect of scale on ES distribution patterns and their spatial relationships has been highlighted in different works (e.g., Martín-López et al., 2009; Geijzendorffer et al., 2015). As ES are generated by different ecosystem types and ecological processes with different spatial patterns, their supply may differ between scales (Hein et al., 2006; Roces-Díaz et al., 2014). Although the analysis of spatial patterns at landscape and regional scales is extensively developed through spatial statistics, landscape metrics and spatially explicit models (e.g. Wagner and Fortin, 2005; Uuemaa et al., 2009; Fortin et al., 2012; Uuemaa et al., 2013), there is a limited knowledge on what are the most appropriate scales of analysis to assess ES and their spatial relationships for different applications in the context of land management, policy and decision making (Andrew et al., 2015; Schröter et al., 2015).

Importantly, scale effects cannot only affect the absolute values of ES indicators but also the relationships among them (Xu et al., 2017). When the provision of a given ES is increased at the expense of another ES a trade-off occurs, while a mutual positive relationship, in which both ES increase at the same time, can be defined as a synergy (Rodríguez et al., 2006; Bennett et al., 2009). Previous work did not find large differences on the relationships between ES patterns and biodiversity comparing different pixel sizes (Anderson et al., 2009), and similar ES patterns across different administrative levels and spatial scales has been reported (Raudsepp-Hearne and Peterson, 2016). It is unknown, however, whether these results can be generalized.

For ES assessments to be useful for planning and management objectives they need to be conducted at relevant spatial scales, which frequently correspond to administrative levels, as those facilitate policy implementation (Tolvanen et al., 2014). The UN Strategic Plan for Biodiversity 2011–2020 urges subnational administrations to consider the development of biodiversity strategies to achieve the targets on biodiversity conservation, including the provision of ES (Aichi goal D, CBD, 2011–2020). In this way the role of regional (Schulp et al., 2014), county (Chen et al., 2009) and municipality (Rodríguez-Loinaz et al., 2015; Renard et al., 2015) administrations is becoming more relevant to assess ES and the corresponding policy-making at these subnational levels. At the same time, increasing the spatial level of analysis is at the cost of homogenization of landscape patterns and loss of local information (Diaz-Varela et al., 2009; Díaz-Varela et al., 2016).

In this work we explored the effects of using different spatial levels of analysis on ES patterns and their spatial relationships, in order to improve the integration of the ES framework on national and sub-national strategies for planning and conservation of natural resources. The specific objectives of this work are to: i) analyze the effects of spatial resolution on the spatial patterns of forest ES, including the location of the areas of highest supply (hotspots); and ii) assess the impact of the level of analysis on the relationships (potential trade-offs and synergies) among different ES, and between ES and forest biodiversity. We compare three levels of spatial resolution: local (~1 km^2), municipality and county, using 10 indicators, including seven ES (food and water provision, climate regulation, soil fertility, flood regulation, erosion control and recreation), forest cover and two biodiversity measures (woody plants and bird species richness). Our study area (Catalonia, NE of Iberian Peninsula) is a highly populated and environmentally diverse Mediterranean region. In comparison with other regions in the Mediterranean context, the study area shows high forest cover and population density, and a wide variety of forest types due to the marked altitudinal and climatic gradient in this region.

2. Material and methods

2.1. Study area

Our study area is Catalonia (NE of Spain; Figure 1), an administrative region covering 32,114 km^2 and mainly located in the Mediterranean biogeographic region. Catalonia and its subregional administrations have shared political responsibilities in planning and managing biodiversity and ES. Catalonia has a population of 7.5 million people, most of them living in or around the capital city (Barcelona). It is a mountainous area with an altitudinal range from the sea level to >3000 m. It is a highly forested region (43% of its area is covered by forests), with the main tree species belonging to the genera *Pinus* and *Quercus*. The forests from coastal and low altitude areas are dominated by *Pinus halepensis* and *Quercus ilex*. At mid-altitudinal ranges –from 800 to 1500 m- the main species are *P. sylvestris*, *P. nigra*, *Q. humilis* and *Q. faginea* and also *Fagus sylvatica* in the wettest zones. Finally, at altitudes higher than 1500 m the main species are *P. uncinata* and *Abies alba*. The study area is divided in 41 counties (average extension = 783.1 km^2, range = 114.7–1784.1 km^2) and 947 municipalities (average extension = 33.9 km^2, range = 0.6–302.8 km^2).

2.2. Data sources

In this work, we analyzed the spatial patterns of a series of seven ES indicators (food and water provision, climate regulation, soil fertility, flood regulation, erosion control and recreation) and additional