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Ecosystem service bundles along the urban-rural gradient: Insights for landscape planning and management

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ABSTRACT

A key challenge of landscape planning and management is coping with multiple ecosystem service (ES) potentials and needs in complex social-ecological systems such as urban regions. However, few studies have analyzed both the supply and demand sides of ES bundles, i.e., sets of associated ES that repeatedly appear together across time or space. This paper advances a framework to identify, map and assess ES bundles from a supply-demand approach to inform landscape planning and management. The framework is applied to the Barcelona metropolitan region, Spain, covering five ES and using eleven spatial indicators. Each indicator was quantified and mapped at the municipal level ($n = 164$) combining different proxy- and process-based models. Our results show significant associations among ES, both at the supply and demand sides. Further, we identified five distinct ES supply-demand bundle types and characterized them based on their specific ES relationships and their main underlying social-ecological conditions. From our findings, we contend that land sharing strategies should be prioritized in urban and agricultural areas to increase landscape multifunctionality while assuring the conservation of large periurban forest areas that are critical for delivering a wide range of local ES highly demanded by the urban population.

1. Introduction

A key challenge of landscape planning and management is coping with multiple ecosystem service (ES) potentials and needs in complex social-ecological systems. The last decade has seen increasing attempts to assess the relationships among different ES through the concept of 'ES bundles' (e.g., Chan et al., 2006; Raudsepp-Hearne et al., 2010; Maes et al., 2012; Martín-López et al., 2012; García-Nieto et al., 2013; Renard et al., 2015). An ES bundle has been defined as a "set of associated ES that repeatedly appear together across time or space" (Raudsepp-Hearne et al., 2010:5242; see also Box 1). A key advantage of the ES bundle approach is that it allows to assess potential synergies and trade-offs by analyzing how different ES in a given area are positively or negatively associated (Bennett et al., 2009; Box 1).

Assessment of ES bundles has been mostly applied to the supply side of ES (i.e., considering the ecosystem's potential to deliver ES or its actual flow *sensu* Villamagna et al., 2013; see Box 1) using a spatially explicit approach (e.g., Chan et al., 2006; Raudsepp-Hearne et al., 2010; Maes et al., 2012; Derkzen et al., 2015; Hamann et al., 2015; Queiroz et al., 2015) and, less frequently, also considering a temporal scale (e.g., Haase et al., 2012; Renard et al., 2015). In contrast, studies assessing ES bundles from a demand perspective (i.e., considering the amount of ES required or desired by society *sensu* Villamagna et al., 2013; see Box 1) have generally focused on determining different socio-cultural values (e.g., Martín-López et al., 2012; Iniesta-Arandia et al., 2014), but very few have produced spatially explicit information. The reason behind this disparity probably relates to the lack of a clear methodological framework for quantifying and mapping ES demand (Wolff et al., 2015) in comparison to ES supply (Egoh et al., 2012; Crossman et al., 2013; Malinga et al., 2015).

Even fewer studies have analyzed both the supply and demand sides of ES bundles from an integrated perspective (but see García-Nieto et al., 2013; Castro et al., 2014). Yet, such approach could have important advantages for sustainable landscape planning

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Box 1. Definition of the main concepts discussed in this paper. **ES bundle** is a set of associated ES that are supplied by or demanded from a given ecosystem or area and usually appear together repeatedly in time and/or space (modified from Raudsepp-Hearne et al., 2010).

ES supply represents the capacity or potential of ecosystem's properties and functions to provide a specific bundle of ES within a given time period (modified from Villamagna et al., 2013). In this paper, we consider that ES supply, ES delivery and ES provision are synonymous terms, but these are different to **ES flow**, defined as the ES actually received, used or experienced by people (Villamagna et al., 2013).

ES demand is the amount of an ES required or desire by society (Villamagna et al., 2013). Therefore, the demand of a given ES may exceed its flow (and eventually its supply).

Synergies and trade-offs are situations that arise when the use of one ES directly decreases (trade-off) or increases (synergy) the benefits provided by another. This may be due to simultaneous response to the same driver or due to true interactions among ES (Turkelboom et al., 2016).

ES mismatches are defined as the differences in quality or quantity occurring between the supply and demand of ES (Geijzendorffer et al., 2015).

Green infrastructure (GI) is a boundary concept with various conceptual meanings (Wright, 2011), but here we follow the EU GI strategy definition: "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ES" (EC, 2013).

and management in complex social-ecological systems, including: (1) enhanced capacity to address green infrastructure planning (GI), i.e., the identification of existing crucial ecosystems for ES delivery (Maes et al., 2015); (2) prioritization of key areas for establishing GI projects due to expected mismatches between supply and demand of ES from a bundle perspective (García-Nieto et al., 2013); and (3) better understanding of potential trade-offs and synergies between ES considering both ecosystem's processes and societal needs (Castro et al., 2014).

Considering both the supply and the demand sides of ES bundles can be particularly relevant in urban regions given their high levels of population density and pressure on available land. Assessing ES bundles in these areas can shed light on potential mismatches, trade-offs and synergies possibly driven by urban development processes. Even if urban areas benefit from the appropriation of vast ES providing areas beyond their boundaries (Rees, 1992; Folke et al., 1997), the local supply of ES can contribute to cope with a variety of 'demands', including protection from climate extremes (e.g., moderation of heatwaves and floods), improvement of environmental quality (e.g., air pollution abatement) and healthier lifestyles (e.g., opportunities for recreation and relaxation) (Bolund and Hunhammar, 1999; Gómez-Baggethun et al., 2013; Haase et al., 2014).

The aim of this paper is to advance a framework to identify, map and assess ES bundles from a supply-demand perspective in order to support landscape planning, management, and decision-making in urban regions. Our framework builds on previous methodological approaches (Mouchet et al., 2014) and consists of five main steps: (1) selection, quantification and mapping of suitable ES indicators (both at the supply and demand sides); (2) assessment of spatial ES associations at both sides; (3) identification of relevant ES supply-demand bundle types; (4) analysis of ES spatial patterns along the urban-rural gradient and along a gradient of management or planning strategies; and (5) understanding of the spatial characteristics of ES bundles and their relevance for landscape planning and management. We used the Barcelona metropolitan region, Spain, as case study area, considering a set of five ES and eleven indicators (six at the supply side and five at the demand side).

2. Material and methods

2.1. Case study area

Our research was conducted in the Barcelona metropolitan region (BMR), north-east of Spain (Fig. 1A). The BMR (3,244 km^2) is the most populous urban region on the Mediterranean coast with 5.03 million inhabitants (Statistical Institute of Catalonia, year 2015) distributed among 164 municipalities. Its urban core is constituted by the municipality of Barcelona (1.61 million inhabitants; 101 km^2) and several adjacent middle-size cities characterized by very high population densities (Fig. 1B). The rest of the BMR is mostly structured in lower density towns, including several sprawling urban areas, except for seven dense sub-centers (municipalities between 50,000 and 200,000 inhabitants). Therefore, the BMR can be described as a polinuclear urban region, conceived as a hybrid between the compact and the dispersed urban models (Catalán et al., 2008).

Distribution of land uses and covers in the BMR is shaped by its physical geography. Two systems of mountain ranges (Catalan Coastal Range and Catalan Pre-Coastal Range) run parallel to the Mediterranean Sea coast, mostly covered by Mediterranean forests of Pine and Holm Oak trees, shrubland and grassland. Prominent examples of these ecosystems with high value for ES supply include protected areas such as the Montseny massif (Pre-Coastal Range) which has the highest peaks in the BMR (>1700 m), or the Collserola massif (Coastal Range) which is virtually enclosed by urban land (Fig. 1C). In contrast, coastal and inland plains are mostly covered by urban and agricultural land. For instance, the Llobregat river delta is heavily sealed by urban land and transport infrastructure (e.g., the Barcelona airport), but it still preserves valuable agricultural and wetland areas. The Penedès area (west of the BMR) is an important wine-growing region.

The BMR is one of the regional planning areas of the 'General Territorial Plan of Catalonia' (PTGC, 1995), the uppermost strategic landscape planning instrument in the region of Catalonia. The 'Territorial Metropolitan Plan of Barcelona' (PTMB) was developed following PTGC's guidelines and approved in 2010 by the Government of Catalonia (PTMB, 2010). The PTMB establishes two main planning categories (called "systems") for land use regulation in the BMR: open areas and urban land (Fig. 1D). The open areas planning system (2405 km^2, 74.1% of the BMR) regulates the land protected from urbanization and includes three planning units: (1) Special protection areas (2032 km^2), which consist of land that is highly protected for its ecological and agricultural values, including Natura 2000 sites and other protected areas; (2) Special protection of vineyards (230 km^2), consisting of highly protected land for its landscape and agricultural values for the wine sector; and (3) Preventive protection areas (143 km^2), for urban-rural transitional areas where urban development is restricted, except in certain circumstances. The urban planning system (840 km^2, 25.9% of the BMR) regulates consolidated built-up land (635 km^2) and defines strategies for urban expansion by the delimitation of development areas (205 km^2) that can be subsequently refined by municipalities through so-called local urban master plans.

We contend that the BMR, as a complex social-ecological system, is a suited testing area for the purpose of this research. The manifest heterogeneous spatial distributions of relevant ES providing areas (Mediterranean forests, agroecosystems, etc.) and potential beneficiaries along the urban-rural gradient can provide relevant insights for the integration of a GI perspective into future landscape planning and management instruments.