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Modeling the influence of alternative forest management scenarios on wood production and carbon storage: A case study in the Mediterranean region

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ABSTRACT

Forest ecosystems are fundamental for the terrestrial biosphere as they deliver multiple essential ecosystem services (ES). In environmental management, understanding ES distribution and interactions and assessing the economic value of forest ES represent future challenges. In this study, we developed a spatially explicit method based on a multi-scale approach (MiMoSe-Multiscale Mapping of ecoSystem services) to assess the current and future potential of a given forest area to provide ES. To do this we modified and improved the InVEST model in order to adapt input data and simulations to the context of Mediterranean forest ecosystems. Specifically, we integrated a GIS-based model, scenario model, and economic valuation to investigate two ES (wood production and carbon sequestration) and their trade-offs in a test area located in Molise region (Central Italy). Spatial information and trade-off analyses were used to assess the influence of alternative forest management scenarios on investigated services. Scenario A was designed to describe the current Business as Usual approach. Two alternative scenarios were designed to describe management approaches oriented towards nature protection (scenario B) or wood production (scenario C) and compared to scenario A. Management scenarios were simulated at the scale of forest management units over a 20-year time period. Our results show that forest management influenced ES provision and associated benefits at the regional scale. In the test area, the Total Ecosystem Services Value of the investigated ES increases 85% in scenario B and decreases 82% in scenario C, when compared to scenario A. Our study contributes to the ongoing debate about trade-offs and synergies between carbon sequestration and wood production benefits associated with socio-ecological systems. The MiMoSe approach can be replicated in other contexts with similar characteristics, thus providing a useful basis for the projection of benefits from forest ecosystems over the future.

1. Introduction

Ecosystems provide a range of goods and services that are important for human well-being and environmental health, which are collectively called ecosystem services (ES) (Costanza et al., 1997; TEEB, 2010). Forests deliver multiple, essential ES commonly classified as provisioning (e.g., wood and non-wood products), regulating (e.g., carbon sequestration) and cultural services (e.g., landscape esthetic value) (MEA, 2005; Haines-Young and Potschin,

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ES have become a key concept in understanding the way humans interact with the natural environment (Costanza et al., 2014; Thorsen et al., 2014). Human activities have shaped ecosystems for millennia across the terrestrial biosphere (MEA, 2005), and forest ecosystems are continuously exploited or degraded by human-induced pressures (Foley et al., 2005; Köchli and Brang, 2005; Haberl et al., 2007; Lindner et al., 2010; Deng et al., 2013; Elia et al., 2014; Lafortezza et al., 2013, 2015).

Understanding ES interactions, their trade-offs or synergies, as well as the drivers influencing these interactions represents a challenge for environmental management and can help to identify effective management practices (Rodríguez et al., 2006; Bennett et al., 2009; Garcia-Gonzalo et al., 2015). To this end, trade-off analysis is used to understand how an ES changes as a function of other ES (Rose and Chapman, 2003; Maass et al., 2005; Rodríguez et al., 2006; Ruijs et al., 2013).

The economic value of ES provided by forests has been assessed since the middle of the last century (Clawson and Knetsch, 1966; Hoehn and Randall, 1987; CBD, 2001). More recently, research has been directed at the spatial analysis of ES value. To this end, van der Horst (2006) and Baerenklau et al. (2010), for example, aggregated the economic value of ES with other relevant forest characteristics at the spatial level.

Mapping and quantifying the supply and demand of ES is a key step toward identifying the appropriate institutional scale for decision making (Swetnam et al., 2011) and for delivering the ES concept in environmental institutions (Daily and Matson, 2008; Kroll et al., 2012; Marchetti et al., 2012). The EU Biodiversity Strategy to 2020 has highlighted the need to map and assess the state of ecosystems and their services in Member States from 2014 to 2020 (EC, 2011; Maes et al., 2013, 2014). Thus, standardized methodological approaches are needed to quantify and map ES (Crossman et al., 2013; Drakou et al., 2015) in order to combine the rigor of small-scale studies with the breadth of broad-scale assessments (Chan et al., 2006).

Many studies have investigated the impact of land use change scenarios on ES (e.g., Burkhard et al., 2009) by adopting, for instance, the Integrated Valuation of Environmental Services and Tradeoffs (InVEST) model. InVEST is a large-scale scenario model that simulates variations in biodiversity and ES under different future-oriented land use changes (e.g., Nelson et al., 2009). From global to landscape scale, the InVEST model has been recently used to explore the potential impacts of land use change under alternative policy scenarios (Lawler et al., 2014), evaluate environmental and financial implications for ES provision among different planning scenarios (Goldstein et al., 2012), and assess the impact of conservation policies on biodiversity and habitat quality (Wu et al., 2014). In Europe, the InVEST model has been mainly applied to assess watershed regulating services in the Czech Republic (Harmáčková and Vačkář, 2015) and map pollination services at the landscape scale (Zulian et al., 2013). Many studies have been carried out in the Mediterranean region. For example, in Spain InVEST has been applied to the evaluation of hydrological services, i.e. water quality and quantity (Terrado et al., 2014; Bangash et al., 2013; Marquès et al., 2013). Although the InVEST model is tailored to the need of simulating land use change scenarios and services provision, to date there has been no attempt to apply InVEST for assessing the impact of alternative management approaches on ES provision over time.

In the context of global climate change, understanding how different forest management practices affect the provision of forest ES at different scales still remains a key challenge for decision-makers (Scarascia-Mugnozza et al., 2000; Kolström et al., 2011; Wang et al., 2012, 2013).

Several studies have analyzed the effects of alternative forest management options and harvesting intensities on landscape pattern and habitat suitability (Radeloff et al., 2006; Shifley et al., 2006, 2008). Other studies have used forest management models and tree growth simulation models integrated with a Geographical Information System (GIS) to estimate the impacts of different forest management strategies (e.g., different rotation lengths and different harvesting intensities) on ES to understand the trade-offs and potential synergies among multiple ES (e.g., timber production and carbon sequestration) (Yousefpour and Hanewinkel, 2009; Buma and Wessman, 2013; Cademus et al., 2014) often associated with biodiversity (Seidl et al., 2007; Yousefpour and Hanewinkel, 2009; Temperli et al., 2012; Kašpar et al., 2015) or water yield (Cademus et al., 2014).

In the forestry sector, the most studied ES are timber (or biomass) production and carbon storage and sequestration. Timber and carbon, which are considered indicators for the provisioning and regulating services delivered by forests (Maes et al., 2014), are competing services as an increase in timber production generally determines a reduction in carbon sequestration.

National Forest Inventory (NFI) data have been used to analyze the trade-offs between carbon sequestration and timber production at the national and regional scale (e.g., Backéus et al., 2006; Cademus et al., 2014), but only a few studies have investigated the effects of alternative silvicultural strategies on ES provision at the operational level of the forest management unit (FMU) (Seidl et al., 2007). The possibility of simulating the effect of alternative management strategies on the supply of ES at the FMU scale is crucial, especially in the Mediterranean region which is characterized by small-scale and fragmented ownership structure.

In Italy, only a few studies have explored forest ES. Ferrari and Geneletti (2014), Schirpke et al. (2014), and Häyhä et al. (2015) mapped and assessed multiple ES in Alpine forests (Northern Italy). Morri et al. (2014) evaluated the supply and demand of forest ES between coastal areas and upstream lands in an area of the Apennine Mountains (Central Italy). Zurlini et al. (2014) evaluated land cover transformations, processes and provisioning ES from local to global scale. It is worth noting that these studies lack a standardized approach and do not attempt to upscale results at a broader scale (e.g., regional or national).

In this study, we present a spatially explicit method based on a multi-scale approach (MiMoSe-Multiscale Mapping of ecoSystem services) to assess the current and future potential of a given forest area to provide ES. To this end, we modified and improved the InVEST model in order to adapt input data and simulations to the context of Mediterranean forest ecosystems. Specifically, we integrated a GIS-based model, scenario model, and economic valuation to investigate two ES (wood production and carbon sequestration) and their trade-offs in the Molise region (Central Italy). Spatial information and trade-off analyses were used to assess the influence of alternative forest management scenarios on the investigated services.

2. Materials and methods

2.1. Study area

The Molise region (Central Italy) covering 443,758 ha was chosen as the study area (Fig. 1). The elevation reaches 2050 m a.s.l. in the Matese massif. The climate is temperate, which is typical of the Mediterranean region (Rivas-Martinez, 2004). Forests and other wooded lands cover 32.8% of the study area (Vizzarri et al., 2015). Turkey oak (*Quercus cerris* L.) (40% of the total forest area), downy oak (*Q. pubescens* Willd.) (22% of the total forest area), and European beech (*Fagus sylvatica* L.) (9.5% of the total forest area) are the most widespread Forest Categories (FCs). Coppices account