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An assessment of soil erosion prevention by vegetation in Mediterranean Europe: Current trends of ecosystem service provision

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ABSTRACT

The concept of ecosystem services has received increased attention in recent years, and is seen as a useful construct for the development of policy relevant indicators and communication for science, policy and practice. Soil erosion is one of the main environmental problems for European Mediterranean agro-forestry systems, making soil erosion prevention a key ecosystem service to monitor and assess. Here, we present a spatially and temporally explicit assessment of the provision of soil erosion prevention by vegetation in Mediterranean Europe between 2001 and 2013, including maps of vulnerable areas. We follow a recently described conceptual framework for the mapping and assessment of regulating ecosystem services to calculate eight process-based indicators, and an ecosystem service provision profile. Results show a relative increase in the effectiveness of provision of soil erosion prevention in Mediterranean Europe between 2001 and 2013. This increase is particularly noticeable between 2009 and 2013, but it does not represent a general trend across the whole Mediterranean region. Two regional examples describe contrasting trends and illustrate the need for regional assessments and policy targets. Our results demonstrate the strength of having a coherent and complementary set of indicators for regulating services to inform policy and land management decisions.

1. Introduction

Soil erosion is one of the main environmental problems in European Mediterranean agro-forestry systems (García-Ruiz, 2010) and for the sustainability of important ecosystems (Almagro et al., 2013; Arnaez et al., 2011). Several legislative and scientific initiatives have focussed on this issue since the late 1950s and recently the Thematic Strategy for Soil Protection (TSSP) defined a coherent framework for the assessment of European soils (CEC, 2006). It pointed out the concentration of soil related risks in southern Europe and the absence of a standardized approach to obtain policy relevant indicators (Gobin et al., 2004; Panagos et al., 2014a; Van-camp et al., 2004).

The ecosystem service (ES) concept is an effective communication tool to bridge knowledge between science and policy (Maes et al., 2012; Viglizzo et al., 2012). In the case of soil erosion prevention (SEP), the TSSP recognizes the importance and knowledge gaps related to the contribution of specific ecosystems and ecosystem functions to the mitigation of soil erosion. The ES concept also supports guidelines for the development of policy relevant indicators for international monitoring systems (Reyers et al., 2013; Tallis et al., 2012) because ES indicators that are sensitive to changes in land use, calculated using standardized methods (e.g. Maes et al., 2015), provide critical sources of information for agro-forestry systems under pressure from policy, environmental or climatic drivers (Hill et al., 2008; Navarra and Tubiana, 2013).

Several studies (e.g. Martínez-Harms and Balvanera, 2012) and international initiatives (e.g. the Common International Classification of Ecosystem Services (Haines-young and Potschin, 2013)) are contributing to the development of a coherent indicator set for the mapping and assessment of ES. Under Action 5 of the European Union (EU) Biodiversity Strategy to 2020 (EC, 2011) the Working Group on Mapping and Assessment of Ecosystems and their Services (MAES) was set up to develop an assessment approach to be implemented by the EU and its Member States (Maes et al., 2013, 2014). Supported by a growing scientific literature (Costanza and

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Kubiszewski, 2012; Seppelt et al., 2011), this working group identified the need for more consistent methodological approaches to quantify and map ES and underlined the importance of finding indicators of ES provision (Müller and Burkhard, 2012) that are sensitive to measure policy impacts (Dunbar et al., 2013; Maes et al., 2012).

Vegetation regulates soil erosion and thereby provides a major contribution to Mediterranean agro-forestry system's sustainability (Iglesias et al., 2011; Olesen et al., 2011). However, the regulation of soil erosion is projected to decrease in the coming decades in the region due to overgrazing, forest fires, land abandonment, climate change, urbanization or the combination of these drivers (López-Vicente et al., 2013; Shakesby, 2011). And the intensity of these drivers has increased in the last decade (Bangash et al., 2013; García-Ruiz and Lana-Renault, 2011; Hoerling et al., 2012; Llasat et al., 2010; Otero et al., 2011). Vegetation acts as an ES provider by preventing soil erosion and therefore mitigating the impact that results from the combination of the erosive power of precipitation and the biophysical conditions of a given area. Consequently, to better represent the impacts related to these drivers it is necessary to map not only the capacity for ES provision (e.g. according to land cover type) but also the actual ES provision and the remaining soil erosion (Nelson et al., 2009).

This paper presents a spatially and temporally explicit assessment of the provision of SEP by vegetation in Mediterranean Europe between 2001 and 2013. It provides insights on past and current trends of ES provision and enables the mapping of vulnerable areas. Finally, it demonstrated the strength of having a coherent and complementary set of ecosystem service indicators to inform policy and land management decisions.

2. Methods

2.1. Study area

The Mediterranean Environmental Zones (Metzger et al., 2005) were used to define the geographic extent of the study, which was constrained to continental Europe and a few larger islands due to data availability. The study area corresponds to 1.06 Million km^2 and covers all European Mediterranean countries (Fig. 1). It encompasses three major environmental zones, i.e. Mediterranean Mountains, which experience more precipitation than elsewhere in the Mediterranean, Mediterranean North and Mediterranean South, both characterized by warm and dry summers and precipitation concentrated in the winter months (Metzger et al., 2008a,b). Within the region agriculture is generally constrained by water availability and poor soils, and grasslands, vineyards and orchards are important land cover/use features (Almeida et al., 2013; Panagos et al., 2013).

2.2. Conceptual background

The conceptual approach for mapping and assessment of regulating services used in this paper has recently been described by Guerra et al. (2014), and is summarized in Fig. 2. SEP is provided at the interface between the structural components of the agro-forestry system and its land use/cover dynamics, which help mitigate the potential impacts from soil erosion (Guerra et al., 2014, 2015). This approach combines a strong conceptual framework with the "avoided change" principle, characterizing regulating ES provision as the degradation that does not happen due to the contribution of the regulating ES provider (i.e. the vegetation cover) (Layke et al., 2012).

To assess SEP following this framework it is necessary to first identify the *structural impact* (Υ) related to soil erosion, i.e. the erosion that would occur when vegetation is absent and therefore no ES is provided (Fig. 2a). It determines the potential soil erosion in a given place and time and is related to rainfall erosivity (i.e. the erosive potential of rainfall), soil erodibility (as a characteristic of the soil type) and local topography (Panagos et al., 2011; Ribeiro et al., 2004). Although external drivers can have an effect on these variables, they are less prone to be changed directly by human action.

The *actual ES provision* (*Es*) is a fraction of the total potential soil erosion (i.e. *structural impact*: Υ), and it is determined by the *capacity for ES provision* (e_s) in a given place and time. We can then define the latter as a key component to quantify the fraction of the *structural impact* that is mitigated (Fig. 2b) and to determine the remaining soil erosion (i.e. the *ES mitigated impact* (β_e)). This *capacity for ES provision* is influenced by both internal drivers (including land management options, forest fires, and urban sprawl) and external drivers (including agricultural policy measures, spatial planning, and climate change). A detailed description of the methodological and conceptual frameworks is given in Guerra et al. (2014).

2.3. Indicators of ecosystem service provision

To understand the relation between drivers and the provision of ES, it is essential to translate the dynamics of the agro-forestry systems into a set of process related indicators that express system responses (Müller and Burkhard, 2012; Guerra et al., 2015). We propose a set of eight indicators that describe the different processes that contribute to SEP (Table 1), including indicators describing the state and dynamics of the *structural impact* (Υ), the *ES mitigated impact* (β_e), the *actual ES provision* (*Es*) and the *capacity for ES provision* (e_s). Together, these eight indicators are sensitive to changes in the climatic profile of each region, soil types, topography, management options and environmental drivers. Although all indicators have been produced at a 250 m resolution, these were finally aggregated by summation to a 5 km grid (25 km^2) resolution to better communicate changes and trends in ES provision and to avoid false precision related with the different data quality of the input datasets. In the case of the *capacity for ES provision* the average was used as, considering the adimensional character of this indicator, the sum does not provide any relevant interpretation value.

2.4. Datasets and methodological application

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), a commonly used empirical model for the determination of potential soil losses (Amore et al., 2004; Fistikoglu and Harmancioglu, 2002), was used to calculate SEP between 2001 and 2013. Soil erosion is represented by a set of critical factors given by (Panagos et al., 2011):

$$A = R \times LS \times K \times C \times P$$

where A (ton ha^{-1}) represents the amount of soil loss, R (MJ mm ha^{-1} h^{-1}) the rainfall erosivity, LS (dimensionless) the topographic factor, K (t ha h ha^{-1} MJ^{-1} mm^{-1}) the soil erodibility, C (dimensionless) the vegetation cover factor and P (dimensionless) the conservation practices factor.

For the ES assessment, the *structural impact* (Υ) was calculated using the expression $\Upsilon = R \times LS \times K$ (Prasuhn et al., 2013), and the gradient of *ES mitigated impact* was determined by $\beta_e = \Upsilon \times \alpha$ (where $\alpha = C$ and $e_s = 1 - \alpha$). Technical infrastructure that could reduce impacts locally was not consider given the spatial scale of the study. Following these two expressions the *actual ES provision* (E_s) can be calculated by $E_s = \Upsilon - \beta_e$. Although no absolute measure of soil erosion is obtained, this mathematical formulation will