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Soil natural capital vulnerability to environmental change. A regional scale approach for tropical soils in the Colombian Andes

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ABSTRACT

In recent decades, the literature on ecosystem services has pointed to the need to quantify and characterise Soil Natural Capital (SNC) under different types of land use and cover. This points to the need of understanding the SNC processes which define the provision of ecosystem services, as well as their changes through anthropogenic time. Tropical regions are subjected to a high rate of land use transformation which may change the properties of the soil, and consequently the potential provision of ecosystem services. This paper presents a proposal for the quantification and characterization of SNC through an index of vulnerability to changes in land cover vegetation and their influence on the provision of ecosystem services for the prevention of soil erosion in tropical soils. The proposed vulnerability index considers aspects of the SNC such as the changes produced in the dynamic properties of different soil types under different types of land-use. The proposed analysis was implemented in a basin measuring 1.280 km^2 situated in the department of Antioquia (Colombia) in humid tropical conditions, where 93% of the soil presents andic properties. Understanding the consequences of the land cover changes for the provision of ecosystem services, as well as how to obtain the spatial representation of the vulnerability current from SNC, allow the identification of areas in which the provision of ecosystem services is at risk inasmuch as the definition of land use policies.

1. Introduction

Last years have been witness of the many efforts made to understand the ecological complexity of ecosystems and how the ecosystems functions and processes permit the provision of goods and services that contribute to social wellbeing (Costanza et al., 1997; Daily, 1999; de Groot et al., 2010; Fisher et al., 2009; Millennium Ecosystem Assessment, 2005).

As a result of this effort soil is now being recognised and studied as a system with base processes that allow the provision of different services and benefits to the human communities. (De Groot et al., 2002; Dominati et al., 2010; Haygarth and Ritz, 2009; Palm et al., 2007). The importance given to soil as an ecosystem in recent years has opened new pathways for the integration of soil science into other environmental sciences and the economy (Hewitt et al., 2015). One of the results of this integration is the concept of soil natural capital (SNC). SNC is defined as the permanent flows of energy and materials, which based on physical, chemical and biological processes lead to soil formation (Berrouet et al., 2018). SNC determine i) soil stocks with their inherent and manageable properties, ii) the support processes that ensure ecosystem function, iii) the provision of ecosystem services required for specific land uses, and iv) its response to degradation processes given by natural or anthropic phenomena.

SNC is transformed in anthropogenic time scales by drivers such as land cover vegetation changes which might change the inherent and dynamic properties that characterize it (Robinson et al., 2012) with consequences on its ability to provide ecosystems services (Blaikie et al., 1996; Füssel, 2007; Metzger et al., 2006; Olmos, 2001). The degree to which the ability of an ecological system to maintain the ecosystem functions and services is affected by threats of different types constitutes the vulnerability of the system (Berrouet et al., 2018). SNC vulnerability is defined as the loss of the SNC capacity to maintain the ecosystem functions when facing different threats in a given space and time. SNC vulnerability is determined based on the state of the inherent and dynamic properties of SNC (Berrouet et al., 2018).

The main contribution of this paper is to the literature that links the conceptual frameworks of Ecosystem Services with soil sciences recognizing soils as ecosystems that provide services to society. We use

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the concept of SNC to study the influence of different trajectories of land cover on the properties of SNC that determine the ability of this ecosystem (soil) to provide ecosystem services. To this end we propose a vulnerability index that provides information on how the dynamic properties of the SNC are influenced by the land cover trajectories (Section 2). This is in line with De Groot et al. (2010) who state the importance of developing indexes that measure ecosystems' capacity to provide services as one of the challenges to the study of ecosystem services.

The proposed vulnerability index focuses on erosion control as an ecosystem service provided by SNC.[1] Erosion control is classified as a regulation service (Haines-Young and Potschin, 2013; Millennium Ecosystem Assessment, 2005) and is defined by the MEA (2005) as the service based on the role of the vegetation in soil retention and landslides[2]. Erosion control depends on the maintenance and function of the structure of the SNC, which allow the SNC to self-regulate and remain stable providing the necessary conditions for soil retention under different types of land use and the provision of other services such as provision and cultural services.

It is a well-known fact that actual land cover vegetation is a determinant factor of the erosion rate in a territory. The proposed vulnerability index allows the analysis of how SNC and its associated services are affected not only by the actual land cover vegetation but also by the by the trajectories of land cover vegetation in the past. This vulnerability index of SNC does not constitute a new index for calculating erosion rates but evaluates the state of SNC after changes in land cover vegetation.[3] It also allows the evaluation of the capacity of SNC for providing erosion control in the future given land cover vegetation in the past and scenarios of future land cover vegetation.

The vulnerability index proposed in this manuscript (Section 3) was evaluated in a basin situated in the northern Andes in Colombia, in humid tropical conditions, where 93% of the soil presents andic properties. Understanding the consequences of the land cover changes for the provision of ecosystem services as well as how to obtain the spatial representation of SNC vulnerability, allow the identification of areas in which the provision of ecosystem services is at risk inasmuch as the definition of land use policies.

2. Material and methods. Building an index of SNC vulnerability to changes in land cover vegetation

Soil properties are modified by different processes among which changes in land cover. The current vulnerability can be assessed by building an index following three stages: i) analysis of the different changes or trajectories in land cover over time, ii) selection of the key inherent and dynamic properties of the soil that determine erosion control, iii) analysis of the interaction between these properties and index formulation. In the following paragraphs we describe each of these stages.

2.1. Assessment of the trajectories in land cover

The temporal character of the vulnerability is related to the analysis of the dynamic properties of the SNC as these can change through the use and management of the land cover in anthropogenic time. As such, it is important to know the different land cover trajectories in the study area. This is possible through a multi-temporal analysis of the land cover of the study area allowing the identification of the areas which have remained as vegetation without intervention and the identification of other areas where land cover trajectories have taken place . In the areas without intervention it is possible to characterise the inherent SNC state.

The final product of this phase is a land cover trajectory map obtained by comparing the same pixel of the covers through various years. The information on land cover taken at different points in time for regional basins is not always available. However, it can be generated based on the acquisition of satellite images available on web portals that can be downloaded free of charge. Geographic information technology such as supervised image classification techniques can then be used to generate different categories of land cover with a spatial resolution according to the objectives of the scale of the work.

2.2. Selection of SNC properties that determine its vulnerability

To assess the state of the SNC requires knowledge of the soil properties necessary to provide a specific soil service (Hewitt et al., 2015). As Dominati (2013) points out it is necessary to identify the key properties and the processes behind the services provided by SNC in order to understand how changes in SNC stock generate changes in the ability of supplying services for society. The most commonly soil properties include organic matter content, the percentage of sand, silt, clay, and rocky fragments, the depth of the parent material, water retention capacity, hydraulic conductivity and infiltration, and the depth of the permeable layer (Adhikari and Hartemink, 2016; Jones et al., 2016).

We propose the construction of an index of the current SNC vulnerability to changes in the land cover, based on one inherent property and three dynamic properties. Between the different inherent SNC properties (Dominati et al., 2010), the most important in explaining the phenomenon of erosion is the slope, increasing the potential runoff speed as the gradient increases (Van Remortel et al., 2004). In addition, it has been broadly recognised by its effects in the erosive processes in multiple erosion models (Suárez and Cruz, 2008). The influence of the slope in soil loss –which generally increases exponentially with the inclination- has been confirmed for the tropics (Morgan, 2005; National Research Council (U.S.), 1993)

The three dynamic properties to include in the vulnerability index are the Soil organic matter content, the bulk density, and the available water holding capacity. The above considers the relationship between the changes in land covers and the dynamic properties (Horn and Kutilek, 2009; Kutílek, 2004; Misra and Teixeira, 2001; Strudley et al., 2008) and the need to opt for properties which can be easily and quickly surveyed in regional basins with scarce available information.

[1] There is a lack of a unified definition of the types of ecosystem services provided by the SNC. The service known as "erosion control" (Millennium Ecosystem Assessment, 2005), which is part of the group of regulation services (Guerra et al., 2014; Haygarth and Ritz, 2009; Wallace, 2007), is mentioned in the studies as: "Erosion prevention and maintenance of soil fertility" in TEEB (The Economics of Ecosystems and Biodiversity, see: http://www.teebweb.org/) and "flow regulation" (Haines-Young and Potschin, 2013). In other studies, this service may be implicitly included within other services such as "hydrological control" (Dominati et al., 2010) or as part of the service known as "erosion and flood control" (Adhikari and Hartemink, 2016).

[2] Other authors relate erosion control with the specific role played by the biota (Wall, 2004); with the soil retention function within an ecosystem (Haygarth and Ritz, 2009); with the role of invertebrates in creating surface roughness and biogenic structures (Lavelle et al., 2006), and with the importance of soil structure maintenance to preserve nutrients (Zhang et al., 2007).

[3] Soil erosion rate can be evaluated throughout different methodologies based on physical or empirical based models. Such models allow the spatial representation, for a given time, the rate of soil losses in a specific territory (Almorox et al., 1994, Msaghaa, 2012; de Vente et al., 2013). The results from these type of models do not consider how soil properties are degraded by phenomena like land cover changes modifying consequently the provision of regulation ecosystem services such as erosion control (Palm et al, 2007). The erosion control evaluation using the conceptual frameworks of socio-ecological systems allow the understanding how SNC changes in anthropogenic time and consequently its ability to provide ecosystem services in the future.