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Soil natural capital quantification by the stock adequacy method

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ABSTRACT

A method is presented for assessing soil natural capital based on the principles of land evaluation. Policymakers are adopting concepts of flows of ecosystem services, and the natural capital stocks that support them, to provide more integrated analyses of the trade-offs between environmental, economic, social and cultural outcomes from land use. Soil is frequently overlooked in these analyses. Techniques are needed to quantify and map soil natural capital and their potential to provide ecosystem services to enable the soil science community to more effectively engage with decision-makers. To support this engagement, these techniques need to use available soil survey maps and databases to provide extensive geographic coverage of soil natural capital estimates. The method presented estimates the adequacy of soil natural capital stocks to support the soil processes behind the provision of ecosystem services under a specific land use. A stock adequacy index estimates the degree to which the provision of services is limited by soil natural capital stocks or advantaged by a stock surplus under a given land use. Reference values are derived from a curve of the response of the provision of the service to key soil stocks for a specified land use. These curves are determined from land evaluation and soil quality literature, or by modelling. The method is essentially an extension of land evaluation in which the evaluations are calibrated using an ecosystem approach. The output indices provide information about potential ecosystem services provision, land-use suitability, soil resource use efficiency, and environmental performance. Outputs from the method are demonstrated for a range of soils under pastoral dairy land use in Wairarapa, New Zealand.

1. Introduction

The recognition that soil should be counted as a component of the earth's natural capital (Costanza et al., 1987) opens new avenues for the integration of soil science with other environmental sciences and economics. Soil natural capital (SNC) is emerging as a useful concept for analysing environmental and resource management problems (e.g. Bristow et al., 2010; Millennium Ecosystem Assessment, 2005; Robinson et al., 2009). It needs to be defined and quantified so it can be used to its potential as a tool in guiding the development of land resource policy and management from local to global scales (McBratney et al., 2014; Robinson et al., 2012). Dominati et al. (2010) assisted this process by providing a framework that helps to reveal the relationships between SNC as represented by soil properties, and flows of ecosystem services coming from soil functioning (soil processes), and how external drivers such as climate and land use, impact on the whole soil system.

Samarasinghe et al. (2013) made an inventory of methods for valuing soil ecosystem services and Dominati et al. (2014) demonstrated the application of appropriate methods for the economic valuation of 14 services provided by one soil under a dairy use. Samarasinghe and Greenhalgh (2013) demonstrate that specific SNC stocks can be valued, using data on market land values under specific land use. This is an important result but it is desirable to develop more direct measures that are less affected by the many factors that drive land prices.

Soil natural capital needs to be quantified in such a way that it can be integrated into environmental policy and land management decision-making to inform the provision of ecosystem services. Most of the messages that soil science needs to communicate to other disciplines can already be expressed using existing nomenclature. The natural capital and ecosystem service terminology, however, allow soil science to translate its knowledge into language that is better understood by ecologists and ecological economists. Soil science insights can then be integrated into wider system analyses that involve other components of natural and built ecological infrastructure (Bristow et al., 2010).

The goal of this study is to present a method to quantify and map SNC that directly uses information available in soil survey databases, with results that may be applied to extensive geographic areas. Furthermore the goal is to develop a method that yields an index as a measure of the capability of a soil to provide a service for a specific land use. There is a need to value soil natural capital in monetary terms (McBratney et al., 2014) to be effectively included in environmental accounting. However, this isn't the only way the importance of soils can be recognised. We propose an index for four reasons. First, it

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is important to clarify the relationships between SNC and the dependent soil services under a use. Second, the index provides a quantity that may be used as an objective measure of SNC capability from which monetary values might be derived if needed from a specific use. Third, monetary values can become an impediment in some forums. Non-monetary values, however, are useful for policy and planning professionals in framing regulatory instruments (Samarasinghe et al., 2013). Fourth, monetary valuation can be technically challenging, including issues of non-commensurability, price volatility, double counting, assumptions made by use of proxies, and the effect of choice of valuation methods, time scale and discount rates.

2. Definitions

We define SNC as soil stocks having the capacity to support the provision of ecosystem services required by a specified land use in which sustainable land management practices are assumed (adapted from Dominati et al., 2010). The ecosystem services required by a land use include services relevant to the off-site environment, for example, filtering of nutrients which determines outcomes such as nitrate leaching into rivers, as well as on-site services of more immediate relevance to the land use enterprise, such as, biomass production. Soil natural capital is a natural asset and the soil profile (pedon) is regarded as the basic unit of this asset. We interpret the soil profile as comprising a bundle of soil stocks. Soil stocks are the soil properties that enable soil processes to operate. The stocks are either measured directly or estimated by pedotransfer functions. Soil stocks include inherent stocks that vary over long timescales (e.g. clay content), and manageable, dynamic stocks that vary over short timescales (e.g. soil water content) (Dominati et al., 2010). Soil carbon stocks are familiar for their use in soil carbon inventory, but stocks also include such non-material soil properties as energy (e.g. stored heat) and soil fabric (e.g. total porosity). These directly relate to the mass, energy and organisational components of SNC identified by Robinson et al. (2009). From these stocks and the functioning of the soil ecosystem, flow ecosystem services which are directly useful to humans.

For practical application SNC needs to be quantified across extensive areas of land. The proposed method for estimating SNC is therefore designed to use commonly available information on soil attributes and from spatial databases and normal soil mapping techniques. This approach facilitates the mapping of SNC stocks. Maps of SNC may be presented as soil maps, in either polygon or raster formats. The analysis is made in the context of the soil ecosystem services framework of Dominati et al. (2010), which brought together soil science concepts and the Millennium Ecosystem Framework for ecosystem services (Millennium Ecosystem Assessment, 2005).

The term ‘soil services’ is used in this paper to refer to the ecosystem services provided directly by soils. The difference between functions and services lies in the context of the analysis. A ‘soil function’ (Karlen et al., 1997) is the output of a soil process, or set of soil processes, where the context is the soil system. The concept of ‘function’ describes a combination of “structure and processes, but also represents the potential that ecosystems have to deliver a service” (Braat and de Groot, 2012, p. 6). By contrast, an ‘ecosystem service’ represents ‘something good’ the soil does that, together with other non-soil factors, confers some significant human benefit in the context of the wider ecosystem (Braat and de Groot, 2012; Dominati et al., 2010). We ascribe to the recommended terminology of processes, functions and ecosystem services (Braat and de Groot, 2012; Dominati et al., 2010; Robinson et al., 2009).

3. Method

3.1. Approach

The stock adequacy method for quantification of SNC is based on the principles of land evaluation (FAO, 1976; Rossiter, 1996) and soil quality evaluation (Karlen et al., 1997; Sparling et al., 2004). The proposed method (Fig. 1) is an extension of land evaluation and is quantified relative to the requirements of a specified land use type (FAO, 1976). It is presumed that for adequate sustainable production, the land use type requires the sustainable provision of a specific set of soil services. For effective operation, the soil services need to draw upon a specific set of soil stocks. If these stocks are adequate then the provision of soil services may be sustained, and the specified land use can operate to its potential. The analysis considers soil attributes, but does not consider external drivers such as management or climate. We include measures of the soil water and soil temperature regimes as soil attributes. If the soil stocks are not adequate for the current land use then the soil services provided will be limited and may not prevent or mitigate environmental impacts. A measure of the SNC at a site is derived from an aggregate of adequacy values of the soil stocks under a specific land use.

We make the following conventions. First, that we can identify the appropriate key soil services required by a specific land use and the key soil stocks that support those soil services. Second, the focus of the analysis is the soil — its stocks and soil service outputs. Many factors influence the effective productive output from a land use (Dominati et al., 2010), but wherever possible non-soil limiting factors are not considered. Third, because the focus is natural capital, it is necessary to distinguish natural capital assets provided by nature from the assets added by management by such interventions as irrigation, artificial drainage, or addition of fertilisers and counted as built capital. Fourth, because our goal is to estimate SNC over extensive geographic areas, we have to use existing soil survey data. These data are by necessity classified and mapped using predominantly inherent soil properties (soil capability, McBratney et al., 2014). Manageable soil properties (including the changes caused by additions of built capital) (soil condition, McBratney et al., 2014) vary across the landscape according to the history of land use impacts and the vulnerability of the soil classes to those impacts (Sparling and Schipper, 2002, 2004). This variability is not captured at the scale of regional soil mapping so spatial distinction between manageable properties and inherent properties is not normally possible over extensive areas. We must work with what we have. Until it is possible to predict the dynamic range of manageable soil properties from land use and management practices and map their status and spatial variability, SNC mapping must be based on data that includes both inherent properties with an imprint of manageable soil properties, as provided by a database. Where suitable data on the status of manageable properties are available then the proposed SNC quantification method may be estimated for soil phenoforms (Droogers and Bouma, 1997) based on management data.

1. Define the land use type (LUT). The definition needs to be specific as it influences the choice of soil services required for productive output and sustainable management. Land management practices need to be considered in the definition of land use types. For example, high-intensity, heavy-animal grazing will require specification of the soil's resistance to treading damage, as this is a service required for animal health, the health of the soil, and the quality of pasture production.
2. Select and quantify the soil services required to support and manage the LUT goals of production, as well as maintain natural capital stocks and environmental quality both on-site and off-site.
3. Determine the soil stocks, represented by the soil properties, needed to sustain each soil service. These may be fundamental soil properties measured directly in the field, indirectly by proximal sensing, from laboratory analysis, or derived properties calculated using pedotransfer functions.

   The soil properties that are appropriate for defining the stocks needed to provide a specific soil service may be determined by examination of the interactions between soil properties, the soil processes they influence, and how these processes contribute to the soil service. The identities of such drivers are suggested in the land evaluation literature where mainly inherent stocks have been identified as ‘land qualities’