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Soil function assessment: review of methods for quantifying the contributions of soils to ecosystem services

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ABSTRACT

Soils and their functions are critical to ensure the provision of various ecosystem services (ES). Many authors nevertheless argue that there are a lack of satisfactory operational methods for quantifying the contributions of soils to the supply of ES. In this study, we review ES mapping studies that have taken the roles of soils in ES supply into account, and propose soil function assessment (SFA) methods approved by German Federal States in spatial planning procedures to use in assessments of ES supply. We found 181 ES mapping studies in which the roles of soils in ES supply were considered. At least one soil property was used as an indicator of soil-related ES in 60% of the publications, and 13% of the publications were mainly focused on the roles of soils in supplying ES. More than two soil functions were considered in a minority of cases, indicating that the multi-functionality of soils has barely been taken into account in previous ES studies. Several decades ago, the soil science community has adopted the concept of soil functions to bring different aspects of soil to the fore and to emphasize the multi-functionalities of soils and their vastly different chemical, physical, and biological properties. We provide a set of approved SFA methods that cover the multi-functionalities of soils and are applicable to ES supply assessments. We propose that this set of operational SFA methods is a starting point for quantifying how soil systems underpin the supply of a wide range of ES. The minimal soil dataset required for these SFA methods is relatively small, and much progress has been made nationally and globally over the last decade in improving soil data infrastructure and online access for end users. These improvements will facilitate the incorporation of SFA into ES studies and thereby improve information for land use decisions. We recommend that ES assessments include the essential and multifunctional roles of soils to promote sustainable land use.

Introduction

The ecosystem Service (ES) approach is increasingly used to incorporate ecological sustainability into political decision-making (Grêt-Regamey et al., 2015). In particular, land use policies should foster spatial planning procedures that drive not only new urban areas and transport infrastructure but also take into account ecological aspects such as the provision of essential ES. In this context, quantifications and maps of ES must be transparent and accurate if they are to be accepted and applied with confidence by policy makers. The body of literature dealing with and illustrating the importance of the ES concept is growing, but relatively few data-driven ES studies and ES assessments using appropriate quantification methods have been published (Baveye, 2017; Liekens et al., 2013; Seppelt et al., 2011). Several publications proposed that more effort should be made to develop accurate and practical methods for quantifying ES (Boyanova et al., 2014; Crossman et al., 2013; Daily et al., 2009). There are two noteworthy models including multiple ES – also soil-based ES – that are increasingly used in ES assessment studies: The Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST) (Sharp et al., 2014) and the Artificial Intelligence for Ecosystem Services model (ARIES) (Villa et al., 2014). ES are increasingly incorporated into political instruments (Bouwma et al. 2017) and there is a particular need for spatially explicit ES quantifications for use in land-use planning to support the sustainable use of also soil resources (van der Biest et al., 2013; van Wijnen et al., 2012).

1.1. Soil is important for ES supply

Soils are critical to various ecosystem goods and services and underpin the delivery of a wide range of ES, including food production, water and climate regulation, energy provision and biodiversity

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(Haygarth and Ritz, 2009; Grêt-Regamey et al., 2016a; McBratney et al., 2014; Volchko et al., 2013). Soil is the skin of the earth and the central interface between atmosphere, hydrosphere, lithosphere and biosphere.. Therefore, soil contributes to many ES (Bouma, 2010; Dominati et al., 2014), and several publications stress that human wellbeing relies greatly on soil resources (Amundson et al., 2015; Banwart, 2011). Huber and Kurzweil (2012) and Dominati et al. (2010) suggested that soil needs to be integral to ES assessments, and soils importance in this regard has been highlighted in several studies (Adhikari and Hartemink, 2016; Bouma, 2014; Bouma et al., 2012; Haygarth and Ritz, 2009; Hewitt et al., 2015; Robinson et al., 2013). Bouma et al (2015) demonstrated the importance of soil and the use of soil information for six case studies clearly showing the necessity to include soil in ES assessments.

1.2. Integration of soil in assessments of ES supply

Soil has hardly been considered or has not been well represented in previous ES studies (Breure et al., 2012; Dominati et al., 2010). Although "soil formation" or "soil fertility" were explicitly mentioned as services in publications by MEA (2005), CICES (2013), Crossman et al. (2013), de Groot (2011) and Haines-Young and Potschin (2008), operational tools for quantifying soil-related ES were not provided in these studies. A number of recently published literature reviews have focused on evaluating ES mapping tools (Bagstad et al., 2013; Crossman et al., 2013; Grêt-Regamey et al., 2016a; Grêt-Regamey et al., 2016b Nelson and Daily, 2010; Vigerstol and Aukema, 2011; Waage et al., 2011) or on providing overviews of ES mapping case studies (Egoh et al., 2012; Layke et al., 2012; Martínez-Harms and Balvanera, 2012; Pagella and Sinclair, 2014; Sch & gner et al., 2013; van den Belt and Blake, 2014). The question of whether and how soil is incorporated into ES studies was not addressed in these reviews. Adhikari and Hartemink (2016) recently reviewed the literature on the relationships between soils and ES and compiled the key soil properties related to individual ES. However, these authors did neither provide operational methods for quantifying the contributions of soils to ES and linking soil properties to ES.

1.3. Soil functions

In the ES community, soils are often called 'natural capital stocks' to value and quantify their contributions to ES (e.g., Hewitt et al., 2015; Robinson et al., 2009, 2013). In the last two decades the soil science community has adopted the concept of soil functions to place value on the roles soils play in sustaining the wellbeing of humans and of society in general (Bouma, 2014; FAO and ITPS, 2015; Haygarth and Ritz, 2009). Soil functions are closely related to soil quality, which was defined by an American Soil Science Society working group in 1995 as "the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries…" (Karlen et al., 1997), emphasising the multi-functionality of soils and their chemical, physical and biological properties. The capacity of soils to deliver ES is largely determined by its functions, and each individual soil function can be seen as providing a soil-related contribution to ES (Bouma, 2014). The soil science community has been developing an understanding of soil systems for more than 100 years (Hartemink, 2015), and closely related concepts, such as soil quality indicators, soil health and soil protection,were developed some decades ago (Doran, 2002; Karlen et al., 2003; Wienhold et al., 2004).

The European Commission's soil protection strategy (EC, 2006) was an important initiative that brought the concept of soil functions to the attention of the wider public and placed the concept on the political agenda, even though the strategy was not later adopted. Seven soil functions were defined in the strategy (EC, 2006): (i) production of food and biomass, (ii) storage, filtering and transformation of compounds, (iii) habitats for living creatures and gene pools, (iv) the physical and cultural environment, (v) source of raw materials, (vi) carbon pool, and (vii) archive of geological and archaeological heritage.

Koch et al. (2013) and McBratney et al. (2014) recently proposed an integrative framework termed 'soil security', aimed at maintaining and optimising soil functionality to value the contributions of soils to environmental and social benefits. The authors defined soil security as "… the maintenance and improvement of the global soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability, and to maintain the biodiversity and the overall protection of the ecosystem". The soil security framework can therefore be seen as one soil-related component in the overall ES approach defined by MEA (2005). The roles of soils in ES were highlighted in the United Nations sustainable development goals for 2015–2030 in goal 15, "….to protect, restore and promote sustainable use of terrestrial ecosystems…" (United Nations, 2015). Nevertheless, it is still challenging to move from these general, theoretical frameworks to specific operational approaches that can be applied in practice.

1.4. Outline and objectives

In the following, we review ES mapping studies that take into account the roles of soils in delivering ES, compile how soil functions were linked to ES in the studies, and identify the main gaps concerning the assessment methods. The aim of this review is to support the quantification and mapping of soil-related ES. To address the main gaps in the assessment methods, we gathered soil function assessment (SFA) methods from the applied soil science community in selected European countries, and provide a selection of assessment methods that are applicable to ES assessment studies. Finally, we discuss what soil data is required by the assessment methods and the sources of available data from global to local scale.

2. Definitions and methods

2.1. Search of the literature published by the ecosystem service community

We combined several information sources for our search of ES studies that consider soil-related issues. We first screened literature reviews of ES mapping and quantification provided by the Ecosystem

Table 1
Reviews of ecosystem services (ES) assessment and mapping (n = 15).

Review type	Authors
ES mapping studies	Crossman et al. (2013), Egoh et al. (2012), Martínez-Harms and Balvanera (2012), Pagella and Sinclair (2014), Sch & gner et al. (2013) and van den Belt and Blake (2014)
ES assessment tools	Bagstad et al. (2013), Nelson and Daily (2010), Vigerstol and Aukema (2011) and Waage et al. (2011)
ES indicators	Layke et al. (2012)
Framework for mapping and assessing ES (not focused on soil)	Maes et al. (2012)
Framework for mapping and assessing ES (focused on soil)	Adhikari and Hartemink (2016), Jónsson and DavíÐsdóttir (2016) and Schwilch et al. (2016)