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Linking soils to ecosystem services — A global review

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ABSTRACT

Soil plays a crucial role in ecosystem functioning. In the 1990s ecosystem services (ES) research focused on developing the concept and framework and only a few studies linked soil properties to ecosystem services. This study reviews the literature on the relationship between soils and ecosystem services and aims to contribute to the scientific understanding on soil and ecosystem services and their interrelations. Most studies have focused on provisioning and regulating ES relating to soil physico-chemical properties. Cultural services had only a few studies, and supporting services were mostly related to soil physico-chemical and biological properties. The number of ES papers increased rapidly after 2000 and in the past 5 years, regulating services such as carbon sequestration, climate and gas regulations, were commonly studied. Once the concept was established in the 1990s, studies focusing on the assessment, valuation, and payments of services became more prominent. Most soil-ES research is published in *Geoderma*. Soil scientists seems to be hesitant to use the term 'ecosystem services' even if their research is devoted to linking soils to ecosystem services. We suggest that future ES research should focus on exploring soil functional diversity of soil biota and the spatial aspects of soil properties to lower level ecosystem services (e.g., water purification, gene pool, and climate regulation). Soil scientists should engage professionals from other disciplines to further promote the contribution of soils to ecosystem services delivery and human well-being. ES soil studies could be used in local and national policy development and program on natural resource use and management.

Contents

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1. Introduction

Ecosystem provides a wide range of goods and services to the benefits of human-kind (Costanza et al., 1997; MEA, 2005). There is now broad agreement how these services are to be grouped. The 2005 Millennium Ecosystem Assessment grouped ecosystem services into four categories: (i) provisioning services (direct or indirect food for humans, fresh water, wood, fiber, and fuel); (ii) regulating services (regulation of gas and water, climate, floods, erosion, biological processes such as pollination and diseases); (iii) cultural services (esthetic, spiritual, educational and recreational); and (iv) supporting services (nutrient cycling, production, habitat, biodiversity).

Soils of natural and managed ecosystem are a critical and a dynamic three-dimensional regulatory system that generates a multitude of functions, also called soil functions (Blum, 2005; CEC, 2006). These functions support the delivery of ecosystem services (Hannam and Boer, 2004). Soil is one of the most complex biomaterials on earth (Young and Crawford, 2004), and a key component of the terrestrial ecosystem operating at the interface of the lithosphere, biosphere, hydrosphere, and atmosphere (Szabolcs, 1994). In spite of its importance, most studies (Costanza et al., 1997; de Groot et al., 2002; MEA, 2005) have described ecosystem focusing on the services only (i.e., provisioning, supporting, regulating, and cultural services) with little emphasis on soil. We have considerable knowledge about soils, its formation and distribution, but our understanding on its functions and soil ecosystem services is incomplete (Daily et al., 1997; Swinton et al., 2006). Hewitt et al. (2015) mentioned that soil is as an overlooked component in ecosystem services studies and policy level decisions. Daily et al. (1997) suggested that soils are one of the important determinants of a nation's economic status, and that the inclusion of soils in ecosystem services frameworks and policy and decision-making is essential. The need for soil ecosystem services assessment and promoting soil–ecosystem linkage in the development of land resource policy and management was emphasized by McBratney et al. (2014) and Robinson et al. (2012). Using the UN-Sustainable Development Goals (SDGs), Bouma et al. (2015) emphasized soil science contribution to ecosystem services in the Netherlands and Italy.

Soil has been termed as a natural capital or stock yielding a sustainable flow of useful goods and services (Dominati et al., 2010; Palm et al., 2007; Robinson et al., 2009). Dominati et al. (2010) suggested a framework to quantify soil natural capital in which soil properties, soil processes, and drivers were linked. Most studies on the valuation of ecosystem services lack a soil component or the soil component is poorly defined or too generalized (e.g., Liu et al., 2010; Winkler, 2006).

Only a few studies have linked soil properties to ecosystem services. The majority of these studies were relating soils to the defined soil functions that ultimately determined the delivery of ecosystem services. The relationship between soil carbon, soil biota, soil nutrient cycling, and moisture retention to ecosystem services has been well documented (e.g., Barrios, 2007; Ghaley et al., 2014; Khanna et al., 2010; Krishnaswamy et al., 2013; Marks et al., 2009; van Eekeren et al., 2010; Williams and Hedlund, 2013). Similarly, the spatial aspects and dynamics of soil properties to ecosystem services have been studied through mapping or scenario modeling of future changes. Instead of using soil information directly, some of the mapping and modeling exercises used environmental variables as a proxy to soil information (Deng et al., 2011; Egoh et al., 2008; Guerra et al., 2014; Sumarga and Hein, 2014; e.g., Trabucchi et al., 2014). The most commonly used proxy is the land use and land cover (LULC) data (Plieninger et al., 2013; Schägner et al., 2013; Seppelt et al., 2011) which have been found useful in regions where data are scarce (Vrebos et al., 2015). LULC data are often favored to produce spatially distributed biophysical parameter values needed for production function models, e.g., many of the InVEST models (Kareiva et al., 2011). In other studies, the use of soil

Table 1
Ecosystem services as categorized by the Millennium Ecosystem Assessment (MEA, 2005), the Economics and Ecosystems and Biodiversity (TEEB, 2010), and the Common International Classification Services (CICES, 2011).

Ecosystem services	MEA categories	TEEB categories	CICES categories
Provisional services	Food, fodder	Food	Biomass (nutrition, animal and plant materials for agriculture use)
	Fresh water	Water	Water (nutrition, drinking, and non-drinking purposes)
	Fiber, timber	Raw materials	Biomass (materials from plants and animals for direct use and processing)
	Biochemical	Medicinal resources	Biomass (materials from plants and animals for direct use and processing)
	Genetic resources	Genetic resources	Biomass (genetic materials from all biota)
	Ornamental resources	Ornamental resources	Biomass (materials from plants and animals for direct use and processing) Biomass based energy sources Mechanical energy (animal based)
Regulating and supporting services (MA)	Air quality and gas regulation	Air quality and gas regulation	Mediation of gas and air flows
Regulating services (TEEB)	Water purification and treatment	Waste treatment (water purification)	Mediation of waste, toxics, and other nuisances by biota, and by ecosystem
Regulating and maintenance services (CICES)	Water regulation	Regulation of water flows	Mediation of liquid flows
	Erosion regulation	Moderation of extreme events	Mediation of mass flows
	Climate regulation	Erosion prevention	Atmospheric composition and climate regulation
	Pollination	Climate regulation	Life cycle maintenance, habitat and gene pool protection
	Pest and disease regulation	Pollination	Pest and disease control
	Primary production	Biological control	Life cycle maintenance, habitat and gene pool protection
	Nutrient Cycling	Life cycle maintenance (migratory species) Genetic diversity maintenance	Soil formation and composition, maintenance of water condition
Cultural services (MA)	Spiritual and religious values	Spiritual experience	Spiritual and/or emblematic
Cultural and amenity services (TEEB)	Esthetic values	Esthetic information	Intellectual and representational interactions
	Cultural diversity	Inspiration for culture, art and design	Intellectual and representational interactions
	Recreation and ecotourism	Recreation and tourism	Spiritual and/or emblematic
	Knowledge system and educational values	Information for cognitive development	Physical and experimental interactions Intellectual and representational interactions Other cultural outputs (existence, bequest)