Ecological Indicators 67 (2016) 586–597

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Operationalizing ecosystem services for the mitigation of soil threats: A proposed framework

Gudrun Schwilch[a,*], Lea Bernet[a], Luuk Fleskens[b,c], Elias Giannakis[d], Julia Leventon[e,f], Teodoro Marañón[g], Jane Mills[h], Chris Short[h], Jannes Stolte[i], Hedwig van Delden[j,k], Simone Verzandvoort[l]

[a] Centre for Development and Environment CDE, University of Bern, Hallerstrasse 10, 3012 Bern, Switzerland
[b] Soil Physics and Land Management Group, Wageningen University, The Netherlands
[c] Sustainability Research Institute, School of Earth and Environment, University of Leeds, UK
[d] Energy, Environment and Water Research Center, The Cyprus Institute, Cyprus
[e] Faculty of Sustainability, Leuphana University, Lüneburg, Germany
[f] Sustainability Research Institute (SRI), School of Earth and Environment, University of Leeds, UK
[g] Institute of Natural Resources and Agrobiology, CSIC, Seville, Spain
[h] Countryside and Community Research Institute, University of Gloucestershire, UK
[i] NIBIO – Norwegian Institute of Bioeconomy Research, Environment and Climate Division, Norway
[j] Research Institute for Knowledge Systems, Maastricht, The Netherlands
[k] School of Civil, Environmental and Mining Engineering, The University of Adelaide, Australia
[l] Alterra – WUR, Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 18 July 2015
Received in revised form 1 March 2016
Accepted 5 March 2016
Available online 25 April 2016

Keywords:
Ecosystem services
Soil functions
Soil threats
Land management
Decision support
Europe

ABSTRACT

Despite numerous research efforts over the last decades, integrating the concept of ecosystem services into land management decision-making continues to pose considerable challenges. Researchers have developed many different frameworks to operationalize the concept, but these are often specific to a certain issue and each has their own definitions and understandings of particular terms. Based on a comprehensive review of the current scientific debate, the EU FP7 project RECARE proposes an adapted framework for soil-related ecosystem services that is suited for practical application in the prevention and remediation of soil degradation across Europe. We have adapted existing frameworks by integrating components from soil science while attempting to introduce a consistent terminology that is understandable to a variety of stakeholders. RECARE aims to assess how soil threats and prevention and remediation measures affect ecosystem services. Changes in the natural capital's properties influence soil processes, which support the provision of ecosystem services. The benefits produced by these ecosystem services are explicitly or implicitly valued by individuals and society. This can influence decision- and policymaking at different scales, potentially leading to a societal response, such as improved land management. The proposed ecosystem services framework will be applied by the RECARE project in a transdisciplinary process. It will assist in singling out the most beneficial land management measures and in identifying trade-offs and win–win situations resulting from and impacted by European policies. The framework thus reflects the specific contributions soils make to ecosystem services and helps reveal changes in ecosystem services caused by soil management and policies impacting on soil. At the same time, the framework is simple and robust enough for practical application in assessing soil threats and their management with stakeholders at various levels.

1. Introduction

The mitigation of soil threats – such as erosion, compaction, salinization, sealing, contamination, or the loss of organic matter, to name just a few – is an increasingly challenging task for the global community, especially in light of population growth and climate change. Productivity goals related to immediate human needs often negatively affect long-term environmental

* Corresponding author. Tel.: +41 316315459.
E-mail addresses: gudrun.schwilch@cde.unibe.ch (G. Schwilch), luuk.fleskens@wur.nl (L. Fleskens), e.giannakis@cyi.ac.cy (E. Giannakis), teodoro@irnase.csic.es (T. Marañón), jmills@glos.ac.uk (J. Mills), cshort@glos.ac.uk (C. Short), jannes.stolte@nibio.no (J. Stolte), hvdelden@riks.nl (H. van Delden), simone.verzandvoort@wur.nl (S. Verzandvoort).

http://dx.doi.org/10.1016/j.ecolind.2016.03.016
1470-160X/

sustainability (Foley et al., 2011). The concept of ecosystem services describes the benefits people obtain from ecosystems (MEA, 2005) and is suitable to illustrate the dependence of human well-being on ecosystems. Considering ecosystem services is thus crucial when improving agricultural production systems in order to reduce yield gaps (Bennett et al., 2010; Bommarco et al., 2013). In addition, soils, being part of the natural capital, provide or contribute to a multitude of ecosystem services that range far beyond agricultural production. Without the ecosystem services provided by soils, for example, we would have neither clean drinking water, nor adequate protection from floods. Nonetheless, the various values of soils are often underestimated (Robinson et al., 2014) and remain largely unrecognized.

Given the importance of soils, their protection has enormous significance for human well-being and our social and economic development. To date, however, land management planning and the implementation of practices to mitigate soil threats do not take sufficient account of ecosystem services provided by soils (MEA, 2005; Schulte et al., 2014; FAO and ITPS, 2015). Efforts to use soil sustainably and preserve its ecosystem services are at the core of the EU research project RECARE (Preventing and Remediating Degradation of Soils in Europe through Land Care, 2013–2018, www.recare-project.eu). To this end, RECARE aims to measure how soil ecosystem services are affected by degradation and conservation. RECARE is engaging with stakeholders in a transdisciplinary process to develop and select appropriate methods to measure, evaluate, communicate and negotiate the services we obtain from soils, with the ultimate aim of improving land management. This research process requires a sound understanding of the ecosystem services concept and the current scientific debate on the assessment and valuation of ecosystem services. A review of this debate and the creation of an adapted framework for operationalizing the ecosystem services concept for soil threats and land management lay the foundation for the project.

Despite various research activities around the world over the last decades, integrating the concept of ecosystem services into land management decision-making continues to pose considerable challenges, and a coherent approach to assessing and valuing ecosystem services is still lacking (de Groot et al., 2010). Many different frameworks have been developed to operationalize the concept, but these are often specific to a certain issue (e.g. biodiversity, water) or level (e.g. national) and each have their own definitions and understandings of particular terms. The task of an ecosystem services framework is to aid the identification of services, as well as their role, values, and trade-offs therein, in order to inform policy and land management decisions. This article reviews existing frameworks and approaches and proposes an adapted framework for soil-related ecosystem services that is suited for practical application in the prevention and remediation of soil degradation across Europe. After briefly introducing the emergence of the ecosystem services concept, we review and compare existing ecosystem services frameworks and evaluate their concepts and terminologies (Section 2). Section 3 focuses on soil aspects and on the contradictory use of soil functions versus ecosystem services, while reviewing the current state of the art and identifying knowledge gaps. We then evaluate existing approaches to monitor and value ecosystem services (Sections 4 and 5, respectively). Furthermore, we examine how the ecosystem services concept has been operationalized in research projects and land management in Europe so far (Section 6). Based on our review, we develop a framework for considering soil ecosystem services that is applicable to all soil threats and land management contexts (Sections 7 and 8), and reflect on how to operationalize this framework for practical application, particularly to support decision-making in preventing and remediating soil degradation in Europe (Section 9). We conclude with an outlook on how the new framework could support ongoing global efforts (Section 10).

2. Comparing ecosystem services frameworks

The ecosystem services concept is considered a useful tool to communicate and highlight the dependence of human well-being on ecosystems. It has the potential to bridge the gaps between ecological, economic, and social perspectives and enable sustainable resource management (Braat and de Groot, 2012). Its most recent definition as proposed by Braat and de Groot (2012, p. 5) states that 'Ecosystem services are the direct and indirect (flux of) contributions of ecosystems to human well-being.' The term 'ecosystem services' was first proposed in the early 1980s to increase public awareness about the negative consequences of biodiversity loss on human well-being (Ehrlich and Ehrlich, 1981; Mooney and Ehrlich, 1997).

Since the 1990s, the number of scientific papers addressing ecosystem services has increased exponentially (Vihervaara et al., 2010), with the focus expanding to include natural capital beyond biodiversity (Fisher et al., 2009). Economists recognized that ecosystems' contributions to human well-being were more wide-ranging than previously thought and thus heavily undervalued in decision-making (Braat and de Groot, 2012).

The release of the Millennium Ecosystem Assessment (MEA) (2003, 2005) finally led to broad recognition of the need to integrate ecosystem services in policy decision-making (Gómez-Baggethun et al., 2010). The potential of an ecosystem for providing ecosystem services depends on ecosystem functioning, which in turn depends on the ecosystem's biophysical structure (of which soils are a part) and on ecosystem processes (de Groot et al., 2010). The MEA defines four types of ecosystem services as summarized below:

(1) *Provisioning services:* products obtained from ecosystems, including food, fibre, fuel, land, water, medicinal, biochemical, genetic, and ornamental resources.
(2) *Regulating services:* benefits obtained from the regulation of ecosystem processes, including carbon sequestration, erosion control, flood protection, pollination, water purification, and waste management.
(3) *Cultural services:* non-material benefits that individuals obtain from ecosystems (through use and non-use), including spiritual, religious, and cultural heritage, as well as recreation, tourism, landscape, and amenity.
(4) *Supporting services:* services that are necessary for the production of all other ecosystem services, such as soil formation and retention, cycling processes, and habitat provision.

The identification and assessment of processes driving the degradation of ecosystem services directly (land use change, climate change, spread of exotic species, contamination, etc.) or indirectly (demographic change, socio-economic change, etc.) were recommended as a basis for decision-making (MEA, 2005).

Critics of the MEA's approach state that this classification mixes processes for achieving services (means) and the services themselves (ends) in the same categories; for example, water regulation is a process to achieve potable water (Wallace, 2007). To achieve practical applicability, operationalization frameworks need to distinguish between intermediate services (e.g. water regulation), final services (e.g. provision of clean water), and benefits (e.g. drinking water) (Boyd and Banzhaf, 2007; Fisher et al., 2009). In response to these criticisms, another large collaborative initiative, The Economics of Ecosystems and Biodiversity (TEEB) (TEEB, 2010), developed a new cascading framework that distinguishes between the biophysical structure, functions, services, benefits, and values