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On the value of soil biodiversity and ecosystem services

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A B S T R A C T

This paper provides a framework to understand the source of the economic value of soil biodiversity and soil ecosystem services and maps out the pathways of such values. We clarify the link between components of the economic value of soil biodiversity and their associated services of particular relevance to soils. We contend that soil biodiversity and associated ecosystem services give rise to two main additive value components in the context of risk and uncertainty: an output value and an insurance value. These are illustrated with examples from soil ecology and a simple heuristic model. The paper also points towards the challenges of capturing such values highlighting the differences between private (individual) and public (global) sources of value.

1. Introduction

There is a nascent interest in the value of soil biodiversity and soil ecosystem services (Daily et al., 1997; Barrios, 2007; Dominati et al., 2010; Clothier et al., 2011; Brussaard et al., 2012). Soil biodiversity here is defined as "the variation in soil life, from genes to communities, and the ecological complexes of which they are part, that is from soil micro-habitats to landscapes" (Turbé et al., 2010). Soil ecosystem services refer to the actions of soil organisms in providing various known ecosystem processes that benefit people. Research activities over decades have shown that soil diversity influences ecosystem functions (Mikola et al., 2002), and it is generally hypothesised that soil biodiversity confers resistance and resilience against disturbance and stress (Wall et al., 2012). Some species decompose plant organic matter and thereby promote soil fertility while others provide soil structure through their actions (Barrios, 2007) thus giving rise to the idea of these functions providing with regulating ecosystem services from soils.

In order to promote biodiversity and ecosystem services, discussions on valuing ecosystem services have been extensive in the literature (*e.g.* TEEB, 2010; Wegner and Pascual, 2011). Here we explicitly posit that assessing the plethora of values associated with soil biodiversity through the ecosystem services the soil biota mediate, implies that the idea of value is anthropocentric, thus in the tradition of the Millennium Ecosystem Assessment (MA, 2005) and subsequent frameworks and initiatives, including TEEB (2010) and UKNEA (2011), among others. Here the focus is on shedding light on the role of economic valuation of soil biodiversity and ecosystem services, to allow such values to be made explicit to society in general and policy making in particular. Seeing soil biodiversity from an economic viewpoint however, should not preclude thinking about other legitimate, *e.g.*, ethical/biocentric, reasoning about biodiversity (Díaz et al., 2015).

This paper contributes to bridging two main disciplines through the ecosystem services lense: soil ecology and ecological economics. As a diverse group of academics interested in the conservation of soil biodiversity by applying the ecosystem services lense, we use a simple theoretical economic framework that is well known in the ecological economics community. It is the so-called total economic value framework. Likewise, there is an important body of knowledge associated with soil ecology linking ecological functions and processes of soil biodiversity and its links with soil ecosystem services. However, our experience and thus the motivation for this paper is that soil ecologists, even if starting

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to use the ecosystem services lense, have not until now linked it to basic principles and theories of economics. Likewise, economists, when dealing with the value of biodiversity and ecosystem services, have hardly noticed that soil biodiversity matters and that the framework of valuation under risk and uncertainty is applicable to soil biodiversity. Thus the paper contributes to the ecosystem services literature in bridging these two, until now, largely independent research fields.

The economic value of soil biodiversity stems from the idea that it can be valued as a natural capital asset, from which a flow of soil ecosystem services is produced (Turner and Daily, 2008; Kareiva et al., 2011). When depleting soil biodiversity there will be associated costs to society when mitigating environmental impacts, or to land owners when adding costly inputs due to the decline of soil ecosystem services. If these costs are not accounted for, then land use policies and other policies, that bear an effect on soil biodiversity, would be misguided and society would be misallocating its scarce resources. As with biodiversity in general (Mooney et al., 2005, Daily et al., 2009), understanding the value of soil biodiversity as natural capital can be incorporated into decision-making across temporal and spatial scales.

Valuation of soil biodiversity requires a set of assumptions. First, as with many ecosystem services, soil ecosystem services are regulating (*e.g.* water flow regulation) and supporting services (*e.g.*, nutrient cycling), and these are regarded as *intermediate services*. Provisioning services (*e.g.*, crops, fibre, clean water, climate mitigation) depend on such regulating and supporting services. Thus, mapping out the pathways between soil biodiversity, soil processes and functions and ultimately intermediate and final services is necessary and should be used to avoid double counting of the value of soil ecosystem services (Boyd and Banzhaf, 2007; Fisher et al., 2009). Second, soil ecosystem services have different values to the users of the services, *i.e.*, individuals and society at large, that need to be explicitly accounted for. Third, identifying the short run benefits and costs associated with running down soil biodiversity poses a challenge as the different ecosystem services are realized over different time spans. The different timescales as well as the private/public misfits between perceptions about the need for conserving soil biodiversity and the actual appropriation of such benefits is a powerful reason for policy intervention, as with biodiversity in general (Ferraro and Kiss, 2002).

This paper puts forward a simple conceptual approach to shed some light on the value of soil biodiversity, associated with soil ecosystem services and stresses an economic rationale for addressing the need of alternative policy instruments which could be designed to support soil biodiversity and associated ecosystem services. In this respect we (1) disentangle the key components of the economic value of soil biodiversity and ecosystem services, emphasising the idea of the natural insurance value of soil biodiversity and (2) address how such values impact and are impacted by management and policy to promote soil ecosystem services.

2. Setting the stage for valuing soil biodiversity and ecosystem services

The concept of economic value used here derives from a utilitarian ethics tradition which frames desirable outcomes that maximise individual use or social satisfaction from allocating scarce resources such as soil biodiversity and ecosystem services (Wegner and Pascual, 2011). In this context, soil biodiversity can be considered as a portfolio of resources that build up soil natural capital. Such wealth can be maintained or reduced through investment decisions, often associated with decentralised individual and/or coordinated social land use decisions. Therefore, from a simple economic logic, soil biodiversity can be seen as an economic asset and the flow of soil ecosystem services may be interpreted as the return or interest we receive from that asset (Perrings et al., 2006). Critically, the level of the interest (ecosystem service) changes as the level of the asset (soil biodiversity) changes. Analogously to investors choosing a mix of capital assets to manage uncertain or risky returns, society also needs to make a choice regarding the level of investment in soil biodiversity to manage risk and the associated variability of the flows of soil ecosystem services. Deliberate investments in soil biodiversity by say, a farmer, or a public agricultural extension agency, largely depend on the perception about the expected net returns. Based on the agreements or conflicts of such perceptions, social actors decide about their willingness to trade-off between promoting soil biodiversity and other economically relevant investment activities. Of course, such actions are also mediated by the governance framework in place, be it through informal institutions, or formal ones, including public regulations, market mechanisms or their mixture (Ostrom et al., 1993).

Another key dimension of the value of soil biodiversity has to do with the expected returns from soil ecosystem services as they become concomitantly private and public goods. When managed by an individual land user it delivers ecosystem services that are privately and currently appropriated, and others that are generally appropriated by society at large and by future generations. For instance, soil biodiversity can contribute to crop yields by supporting nutrient delivery or regulating water within a field. This is easily appropriated by an individual farmer. Other benefits arising for instance through the reduction of nutrient losses can be appropriated by individuals outside the farmgate, by reducing soil erosion or eutrophication, which can be considered as a public good. It is well known that public goods tend to be sub-optimally allocated by society especially if such allocation is left to the market logic alone (Cornes and Sandler, 1996).

Valuation of ecosystem services requires ecological insight in quantitative responses from biodiversity through the functioning of soil organisms to provide an associated ecosystem service (Mace et al., 2012). Below we provide two simple examples relevant to the role of soil biodiversity and its connections to soil ecosystem services. The examples illustrate soil biodiversity mediation of privately appropriable ecosystem services (food provisioning, through crop production, and water regulation through water infiltration in soils) and of a publicly appropriable ecosystem service (climate regulation through greenhouse gas control). We focus on key biota, either single species or ‘functional groups’ of earthworms (*sensu* Cummins, 1974), that are considered crucial to a specific soil functions. Earthworms are indeed important in the regulation of soil-borne processes (Spurgeon et al., 2013; Blouin et al., 2013; Lubbers et al., 2013; van Groenigen et al., 2014), therefore their abundance is a proxy in the prediction of the delivery of associated soil ecosystem services.

Theoretically one could assign economic values to the services earthworms generate by relating the change in the stock of earthworms to changes in the services they provide. This would require establishing the biophysical relationships between the earthworms and the functions they provide. Here we show two examples of earthworms providing multiple ecosystem services that are amenable to economic valuation.

2.1. Earthworm mediation of water infiltration in soils (regulation service)

Earthworms play an important role in agroecosystems in influencing soil water infiltration and run-off (Lee, 1985; Chan, 2004). By burrowing, feeding on plant remains or soil organic matter, and by producing casts (excrements deposited on the surface or belowground) they affect soil structure and porosity and