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Developing spatial biophysical accounting for multiple ecosystem services

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A B S T R A C T

Ecosystem accounting is receiving increasing interest as a way to systematically monitor the conditions of ecosystems and the ecosystem services they provide. A critical element of ecosystem accounting is understanding spatially explicit flows of ecosystem services. We developed spatial biophysical models of seven ecosystem services in a cultural landscape (Limburg province, the Netherlands) in a way that is consistent with ecosystem accounting. We included hunting, drinking water extraction, crop production, fodder production, air quality regulation, carbon sequestration and recreational cycling. In addition, we examined how human inputs can be distinguished from ecosystem services, a critical element in ecosystem accounting. Model outcomes were used to develop an ecosystem accounting table in line with the System of Environmental-Economic Accounting - Experimental Ecosystem Accounting (SEEA EEA) guidelines, in which contributions of land cover types to ecosystem service flows were recorded. Furthermore we developed spatial accounts for single statistical units. This study shows that for the case of Limburg spatial modelling for ecosystem accounting in line with SEEA EEA is feasible. The paper also analyses and discusses key challenges that need to be addressed to develop a well-functioning system for ecosystem accounting.

1. Introduction

The importance of protecting ecosystems and the services they provide to sustain human livelihoods is increasingly recognised (MA, 2005; TEEB, 2010; United Nations, 2012) and there is a high demand from policy makers for sound information on ecosystem services (ES) (Larigauderie et al., 2012). A crucial step in meeting the information needs of policy makers is measurement and monitoring of the current status and trends in the delivery of ES. While it is widely recognised that ES contribute to human well-being (MA, 2005), and supports economic activities in multiple ways (e.g. Barbier, 2007; Boyd, 2007; TEEB, 2010), they have not yet been systematically monitored in national accounts. National accounts comprise a system for measuring economic activity, and have been developed over the course of the last half century into a comprehensive statistical standard, that is now widely applied across the world (United Nations et al., 2009). Ecosystem accounting is a promising method to integrate ecosystems and ES into national accounts (Boyd and Banzhaf, 2007; Edens and Hein, 2013). A first guideline for ecosystem accounting was recently developed under auspices of the UN Statistics Commission: the System for Environmental Economic Accounts Experimental Ecosystem Accounting guidelines (SEEA EEA) (European Commission et al., 2013).

Ecosystem accounting measures and monitors the conditions of ecosystems, their capacity to provide services and the ES flows from the ecosystem to society. A key element in the development of methodologies for ecosystem accounting is understanding how ES can be connected to economic activity, and how flows of ES can be quantified at large spatial scales, with an accuracy sufficient for accounting purposes (Boyd and Banzhaf, 2007; Edens and Hein, 2013; Mäler et al., 2008). Ecosystem accounting takes a spatial approach towards analysing ecosystems and ES. The SEEA EEA guidelines recognise that ecosystems and ES are spatially heterogeneous, and that this spatial variability needs to be captured in ecosystem accounting (European Commission et al., 2013). Developing spatially explicit ecosystem accounts is thus a specific policy application of spatial ES modelling.

Spatial ES modelling is a research field which has progressed rapidly in recent years (e.g. Burkhard et al., 2012; Maes et al., 2012; Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Schröter et al., 2014a; Serna-Chavez et al., 2014; Willemen et al., 2010). It addresses a wide range of ES at different spatial scales with a

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variety of services modelled with different spatial methods (Crossman et al., 2013b; Martínez-Harms and Balvanera, 2012; Nemec and Raudsepp-Hearne, 2013). For ecosystem accounting spatial modelling approaches that use quantified data could be used (e.g. Kareiva et al., 2011; Petz and van Oudenhoven, 2012; Sumarga and Hein, 2014). ES mapping studies that rely on proxy indicators for ES (Eigenbrod et al., 2010), or on expert judgement (Burkhard et al., 2012; Seppelt et al., 2011) are less suitable for ecosystem accounting. Spatial modelling of ES for ecosystem accounting calls for a definition of ES that is aligned with the national accounting framework (European Commission et al., 2013), measuring ES flows with quantifiable (spatial) indicators, high resolution, accurate output at large spatial scales (e.g., provinces, nations), and understanding the level of error involved.

The objective of this study is to assess how multiple ES can be spatially modelled and analysed in a way that is consistent with ecosystem accounting, at a large spatial scale. In particular, we test if and how the spatial approach outlined in the SEEA EEA for measuring ES flows from ecosystems to society can be applied at the scale of the Dutch province of Limburg. We test which models would be appropriate to model key ES provided by ecosystems in this province, and discuss what the main challenges and bottlenecks are for further developing ecosystem accounting. We selected Limburg province because it is a data-rich environment, comprising a diversity of landscapes and generating a range of different ES typical for North Western Europe. We analysed seven ES: hunting, drinking water extraction, crop production, fodder production, air quality regulation, forest carbon sequestration and recreational cycling.

2. Conceptual framework and definition of ES

Current conceptualisations of the ES concept (cf. Haines-Young and Potschin, 2010a; further refinements by van Oudenhoven et al. (2012) and van Zanten et al. (2014)) have described the emergence of an ES as a "cascade" from ecosystem properties to ES values. In accounting, ES are "the contributions of ecosystems to benefits used in economic and other human activity" (European Commission et al., 2013). In this definition it is recognised that human contributions, in the form of labour and manufactured capital, are necessary for humans to benefit from many services (Bateman et al., 2011; Boyd and Banzhaf, 2007; Haines-Young and Potschin, 2010b; TEEB, 2010), and that the processed goods (e.g. milk, processed wood or bread) themselves are not the ES (Schröter et al., 2014b).

Disentangling human and ecosystem contributions in the generation of an ES is not straightforward. In line with van Oudenhoven et al. (2012) and Edens and Hein (2013) we argue that two types of human contributions can be distinguished, namely (i) historic and current management of the ecosystem state and (ii) the extraction or use of the ES (Fig. 1). The magnitude of these human contributions depends on the respective ecosystem and ES, but is especially noticeable in cultural landscapes. The current ecosystem state is determined by a combination of ecological properties and human management which often has evolved over the course of centuries. For example, besides ecological properties, the current state of a cropland is determined by current management practices (fertilizer application, irrigation), as well as by the past conversion of a natural ecosystem to cropland. Within an accounting context, past anthropogenic changes to ecosystem properties are reflected in the current state of the ecosystem. Recurrent inputs may be required for generating ES (as in the case of fertilizer inputs required for crop production), and they need to be measured and included in the account as intermediate human input.

For humans to benefit from ES a flow is necessary from the ecosystem to society. For most regulating ES this flow can be fully attributed to the ecosystem, i.e. there is no or hardly any human contribution. For example, forests may sequester carbon without human intervention. For most provisioning and cultural ES, however, a human contribution is necessary for society to benefit. This benefit emerges as a result of the contributions of both the ecosystem and humans, for instance in the form of extraction or other forms of active use (Fig. 1, Bateman et al., 2011; Böhnke-Henrichs et al., 2013). Hence, in accounting there is a need to conceptually describe the contribution of the ecosystem for specific services. In this paper we propose the following. For provisioning services the benefit is a consumable or marketable good, such as harvested crops or logged timber, while the ES would be the standing crop prior to harvest, or the standing stock of trees that will be logged. For provisioning services a human contribution in the form of labour and manufactured capital is necessary to transform an ES into a benefit ("mobilisation"

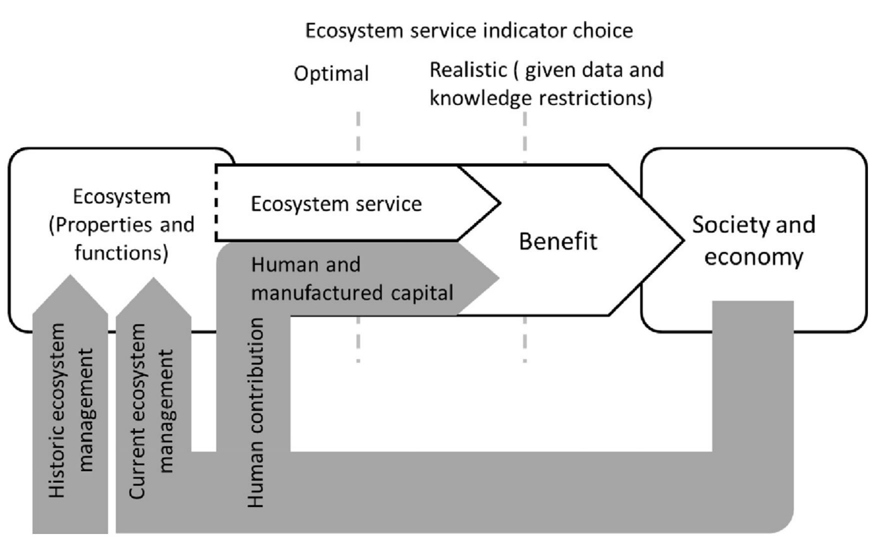

Fig. 1. Framework for conceptualization of human contributions to the emergence of an ecosystem service. Both historic and current management influence ecosystem properties and functions, which in turn has an impact on the ecosystem service. Human and manufactured capital is often needed to realise the benefits that society and economy derives from ecosystems. Indicator choice in empirical ecosystem service assessments often reflects the benefit instead of the contribution of ecosystems to this benefit.