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Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital

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Ecosystem accounting has been developed as a systematic approach to incorporate measures of ecosystem services and ecosystem assets into an accounting structure. Ecosystem accounting involves spatially explicit modelling of ecosystem services and assets, in both physical and monetary terms. A range of recent studies has tested the various elements of ecosystem accounting, and an initial guideline for ecosystem accounting has been prepared under auspices of the UN. This paper summarizes the current knowledge of key aspects of ecosystem accounting, analyses its niche in the overall system for environmental-economic accounting, and provides three examples of how ecosystem accounting can support sustainable development. We also discuss the main limitations of the approach and issues requiring further research.

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Introduction

The ongoing, rapid human modification of ecosystems is having major effects on the services these ecosystems supply to people [1,2]. This has sparked an interest in the development of information systems that allow analysing and tracking the state of ecosystems and the services they provide to people over time [3,4•]. One approach is to adopt information systems based on a natural capital accounting approach (e.g. [5,6]), mirroring the development of economic information systems following the financial crisis of the 1930s. At that time the national accounts were designed to support policy makers designing economic and financial responses to the crisis [7]. The System of National Accounts (SNA) [8] is now an international statistical standard with specific guidelines on how to compile a set of interrelated accounts to record economic activity (e.g. production, consumption, and accumulation of assets).

Ecosystem accounting has emerged as a promising approach to analyse ecosystem capital, or, in the terminology of the System of Environmental-Economic Accounting (SEEA) [5], ecosystem assets. It provides a comprehensive and integrated framework for organising information on ecosystem state and ecosystem use, developed with a direct connection to the SNA. The development of ecosystem accounting is supported by advances in bio-physical modelling and the availability of spatially explicit data sources. It is by its nature a multidisciplinary undertaking bringing together people from a range of disciplines such as statisticians, economists, ecologists and GIS modellers. The connection to the SNA facilitates the integrated analysis of linkages between the environment and the economy.The objective of this paper is to analyse current insights in and experiences with ecosystem accounting, in order to guide further scientific research in this field as well as the design of ecosystem accounting pilots. We base our analysis on a comprehensive literature review of, firstly, scientific papers in the fields of ecosystem services and natural capital accounting; secondly, the various relevant standards and guidelines released under the auspices of the UN Committee of Experts on Environmental-Economic Accounting and thirdly, discussion papers, in particular those of the London Group on Environmental Accounting.[5] In Section ''Defining ecosystem accounting'' we clarify what distinguishes ecosystem accounting from alternative approaches. Section ''The ecosystem accounts'' introduces the main types of accounts that are part of the ecosystem accounting framework and analyses insights provided in recent literature that are relevant for developing these accounts. In Section ''Applying ecosystem accounting in support of environmental management'' we

[4] The views expressed in this paper are those of the authors and do not necessarily reflect the policies of Statistics Netherlands.
[5] See: http://unstats.un.org/unsd/envaccounting/londongroup/.

discuss how ecosystem accounting can inform environmental management. In Section ''Discussion'', we discuss limitations and constraints, and we specify a number of areas that require further research, and Section ''Conclusions'' concludes.

Defining ecosystem accounting

The SEEA is a complementary system to the SNA. It has been developed by the statistical community over the past 25 years, culminating in the adoption in 2012 of the SEEA Central Framework [9] as an international statistical standard by the United Nations Statistical Commission. Environmental-economic accounts complement the national accounts by providing a description of the interdependency of economic activity and the natural environment, in the form of various types of accounts. These accounts include physical flow accounts that describe the supply and use of materials (e.g. water, timber) and energy, as well as the residuals and return flows generated (such as emissions) and asset accounts recording the stocks and changes in stocks of environmental assets.

Ecosystem accounting is a relatively recent development within the SEEA. It can be defined as an integrated approach to measure and monitor ecosystems, and the flows of services from ecosystems into economic and other human activity, in a way that is aligned with the SNA. The alignment with the national accounts as described in the SNA [8] distinguishes ecosystem accounting from various other ecosystem valuation approaches (e.g. [10••,11,12]). Advantages are that this brings a consistent set of definitions for key concepts (see Box 1), facilitates avoiding double counting, and allows comparing outputs from the ecosystem accounts with economic statistics measured in the national accounts. Unlike the SEEA Central Framework [9], ecosystem accounting takes an integrated approach to analysing ecosystem assets, with explicit consideration of the spatial diversity of ecosystems and the interconnectedness of ecosystem components. Ecosystem accounting also includes regulating and cultural services, which are not considered in the Central Framework. Provisional guidelines in the form of the SEEA Experimental Ecosystem Accounting [5] have been developed by a consortium of international agencies, statistical offices and other stakeholders. The guidelines integrate insights from the statistical and academic community about the alignment of the concept of ecosystem services and functions with national accounting principles [3,13,14] as well as ecosystem services modelling [1,15].

Box 1 Key terms in ecosystem accounting

Asset = A store of value representing a benefit or series of benefits accruing to the economic owner by holding or using the entity over a period of time (EC *et al.*, 2009).

Benefits = goods and services that are ultimately used and enjoyed by people and which contribute to individual and societal well-being.

Ecosystem = A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. (Convention on Biological Diversity, Article 2).

Ecosystem capacity = The ability of the ecosystem to generate an ecosystem service under current ecosystem conditions and uses at the maximum level that does not lead to a degradation of ecosystem condition

Ecosystem condition = Overall quality of the ecosystem, as expressed through a set of indicators expressing ecosystem composition and/or ecosystem functioning, e.g. species diversity or net primary production.

Ecosystem service = the contributions of ecosystems to benefits used in economic and other human activity (UN *et al.* [8], 2.23), e.g. providing standing timber for harvesting or air filtration.

Natural capital = The set of renewable (e.g. ecosystems) and non-renewable (e.g. mineral deposits) environmental assets that directly or indirectly produce value or benefits to people.

Many benefits to which ecosystems contribute are already included in economic accounts. For instance, harvested crops, timber harvests and the turn-over of recreation companies are already inside the production boundary used to define GDP [8]. There are three main pieces of information that are captured in the ecosystem accounts that are not in the SNA (see also [16]). First, ecosystem accounting makes the contribution of ecosystems to economic activities explicit. Second, it makes visible several ecosystem services, including various types of regulating services (e.g. carbon sequestration, air filtration) and some cultural services (e.g. recreation) that contribute to benefits that typically lie outside the SNA production boundary. Third, ecosystems are recognized as a form of capital, and the accounts allow tracking changes in ecosystem assets over time (including its degradation or enhancement) thus supporting analysis of sustainable development.

Note that the ecosystem accounting approach differs from the welfare based accounting approach, which aims to measure the contributions of different types of capital (including natural capital) to human welfare, requiring the calculation of shadow prices of assets (e.g. [6,17,18]). In contrast, the SNA-aligned environmental-economic accounting approach uses marginal exchange values to estimate the contributions of environmental assets to economic activity.

The ecosystem accounts

Within the scope of ecosystem accounting lies the measurement of: firstly, the extent and condition of ecosystems; secondly, ecosystems' capacity to generate ecosystem services as a function of extent and condition; thirdly, flows of ecosystem services; fourthly, the connection between ecosystems and economic activity; and fifthly, ecosystem components such as biodiversity [5,16]. The different ecosystem accounts are described below, see also Figure 1 and Box 1. Based on a literature review we present an analysis of the experiences with establishing these accounts to date. The ecosystem accounts — with the