Ecological Indicators 21 (2012) 110–122

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

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

Framework for systematic indicator selection to assess effects of land management on ecosystem services

Alexander P.E. van Oudenhoven[a,∗,1], Katalin Petz[a,1], Rob Alkemade[b], Lars Hein[a], Rudolf S. de Groot[a]

[a] Environmental Systems Analysis Group, Wageningen University, PO Box 47, 6700 AA Wageningen, The Netherlands
[b] Netherlands Environmental Assessment Agency (PBL), PO Box 303, 3720 AH Bilthoven, The Netherlands

ARTICLE INFO

Keywords:
Ecosystem services
Indicators
Land management
Milk production
Air quality regulation
Recreation

ABSTRACT

Land management is an important factor that affects ecosystem services provision. However, interactions between land management, ecological processes and ecosystem service provision are still not fully understood. Indicators can help to better understand these interactions and provide information for policy-makers to prioritise land management interventions. In this paper, we develop a framework for the systematic selection of indicators, to assess the link between land management and ecosystem services provision in a spatially explicit manner. Our framework distinguishes between ecosystem properties, ecosystem functions, and ecosystem services. We tested the framework in a case study in The Netherlands. For the case study, we identified 12 property indicators, 9 function indicators and 9 service indicators. The indicators were used to examine the effect of land management on food provision, air quality regulation and recreation opportunities. Land management was found to not only affect ecosystem properties, but also ecosystem functions and services directly. Several criteria were used to evaluate the usefulness of the selected indicators, including scalability, sensitivity to land management change, spatial explicitness, and portability. The results show that the proposed framework can be used to determine quantitative links between indicators, so that land management effects on ecosystem services provision can be modelled in a spatially explicit manner.

1. Introduction

Ecosystems provide humans with numerous benefits, such as clean water, medicines, food, and opportunities for recreation. The Millennium Ecosystem Assessment (MA, 2005) highlighted the importance of these ecosystem services for sustaining human well-being. The Economics of Ecosystems and Biodiversity study (TEEB, 2010) provided insight in the economic significance of ecosystems. As a result, the ecosystem services concept has now gained importance at the policy level, illustrated by the establishment of the International science-policy Platform on Biodiversity and Ecosystem Services (IPBES), and the incorporation of ecosystem services in the 2020 targets set by the 10th Conference of Parties to the Convention on Biological Diversity (Larigauderie and Mooney, 2010; Mace et al., 2010).

Policy and environmental planning decisions largely influence how land is being managed (Fisher et al., 2008; Carpenter et al., 2009; von Haaren and Albert, 2011). On a regional scale, land management is one of the most important factors that influence the provision of ecosystem services (Ceschia et al., 2010; Fürst et al., 2010b; Otieno et al., 2011). Land management is defined by the presence of human activities, that affects land cover directly or indirectly (Kremen et al., 2007; Olson and Wäckers, 2007; Verburg et al., 2009). It comprises ecosystem exploitation, land use management, and also includes ecosystem management (Brussard et al., 1998; Bennett et al., 2009). Land management refers to human activities; land cover to the biotic and abiotic components of the landscape, e.g. natural vegetation, forest, cropland, water, and human structures (Verburg et al., 2009). Land use refers to the purpose of human activities which make use of natural resources, thereby impacting ecological processes and functioning (Veldkamp and Fresco, 1996). Land management includes but does not equal ecosystem management, because it refers to managing an area so that ecological services and biological resources are conserved, while sustaining human use (Brussard et al., 1998; MA, 2005). Examples of land management include irrigation schemes, tillage, pesticide use, nature protection and restoration. (Follett, 2001; Bennett et al., 2009; Blignaut et al., 2010; Carvalho-Ribeiro et al., 2010; Ngugi et al., 2011).

The analysis of ecosystem services to support land management decisions faces a number of challenges. They include: (1) identifying comprehensive indicators to measure the capacity of

∗ Corresponding author.
E-mail addresses: alexander.vanoudenhoven@wur.nl, alexander.vanoudenhoven@gmail.com (A.P.E. van Oudenhoven).
[1] These authors contributed equally to the work.

1470-160X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2012.01.012

ecosystems to provide services; (2) dealing with the complex dynamics of the link between land management and ecosystem services provision; (3) quantifying and modelling the provision of ecosystem services by linking ecological processes with ecosystem services; and (4) accounting for the multiple spatial and temporal scales of ecological processes and ecosystem services provision (Turner and Daily, 2008; Carpenter et al., 2009; van Strien et al., 2009; Villa et al., 2009; De Groot et al., 2010b; Bastian et al., 2012).

Given these challenges, it is necessary to have a consistent and comprehensive framework for analysing ecosystem services (Ostrom, 2009; Posthumus et al., 2010). A framework provides structure to the research and enables better validation of its outcomes (Bockstaller and Girardin, 2003; Niemi and McDonald, 2004). Furthermore, it is important to formulate a comprehensive set of indicators (Niemeijer and de Groot, 2008; Layke et al., in press) that enables the assessment of land management effects on ecosystem services provision, on different spatial scales (Carpenter et al., 2009; van Strien et al., 2009; De Groot et al., 2010b). With indicators, policy-makers and land managers can be provided with information, based upon which interventions can be identified, prioritised and executed (OECD, 2001; Layke, 2009). Finally, there is a need to test how ecosystem services frameworks can be used for the selection of indicators (Nelson et al., 2009).

The objective of our study was, therefore, to systematically select indicators which can be used to analyse the link between land management and the provision of ecosystem services at multiple scales. To achieve this objective we developed a consistent framework for indicator selection which builds on existing frameworks, in particular by TEEB (De Groot et al., 2010a) and Haines-Young and Potschin (2010).

We first describe our framework and how it can be used for indicator selection. Then we apply it to a case study to assess the effect of land management on ecosystem services provision. Characteristics of and interactions between indicators were studied, and all indicators were evaluated based on a selected set of criteria. The case study was done in a multifunctional rural landscape in the southern part of the Netherlands, where multiple ecosystem services are provided across different spatial scales.

2. Methods

2.1. Framework

Consistent and comprehensive frameworks that link human society and economy to biophysical entities, and include impacts of policy decisions, have been developed during the last decades. For the analysis of ecosystem services such a framework was developed in the context the Millennium Ecosystem Assessment (MA, 2003), which was itself based on a Driver, Pressure, State, Impact Response framework. We adapted the frameworks by TEEB (De Groot et al., 2010a) and Haines-Young and Potschin (2010) for indicator selection. These frameworks are among the most recent and comprehensive ecosystem services asssessment frameworks. The TEEB framework explains the link between biodiversity, ecosystem services and human well-being (De Groot et al., 2010a) and builds on several recent studies (MA, 2003; Braat et al., 2008; Fisher et al., 2008, 2009). The TEEB-study calls for the development of indicators for the economic consequences of biodiversity and land use change (De Groot et al., 2010a; Reyers et al., 2010). The stepwise so-called "cascade-model" by Haines-Young and Potschin (2010) is useful for assessing the provision of ecosystem services in a structured way, linking ecosystem properties to functions and services. Although the importance of land management is acknowledged in (descriptions of) both frameworks, land management is not explicitly included. We therefore adapted the framework by including land management, which enables the selection of indicators for assessing the effects of land management and ecosystem services.

Fig. 1 shows the main elements of our framework: the driving forces, ecosystem, service provision, human well-being, and societal response. The scope of our study is indicated by the white boxes in Fig. 1: land management, ecosystem properties, function and service. Unless stated otherwise, definitions and relations provided are based on or adapted from the TEEB-study (De Groot et al., 2010a). In the framework we use the term "ecosystem". We note, however, that the interactions which we describe below can refer to ecosystems at multiple spatial scales, e.g. at plot, landscape, regional or even national scale (Hein et al., 2006).

Drivers or driving forces are natural or human-induced factors which can influence the ecosystem, either directly (e.g. through climate change or environmental pollution) or indirectly (e.g. through changes in demography or economy) (MA, 2005). Although drivers such as climate change or environmental pollution also have an impact on the ecosystem, we focus in our assessment on the driving force 'land management'. As described earlier, *land management* refers to the human activities that can affect ecosystem properties and function (Kremen et al., 2007; Bastian et al., 2012; Chen et al., 2011), as well as the ecosystem service that can be provided (O'Farrell et al., 2007; Edwards et al., 2011). *Ecosystem properties* are the set of ecological conditions, processes and structures that determine whether an ecosystem service can be provided. Examples include net primary productivity (NPP), vegetation cover, and soil moisture content (Johnson et al., 2002; Kienast et al., 2009). Ecosystem properties underpin *ecosystem functions*, which are the ecosystem's capacity to provide the ecosystem service (De Groot et al., 2010a). An ecosystem function, or "potential" (Bastian et al., 2012), is the subset of ecosystem properties which indicates to what extent an ecosystem service can be provided. Examples of ecosystem functions include capturing of aerosols by vegetation (Nowak et al., 2006) and carbon sequestration (Díaz et al., 2009). The *ecosystem service* contributes to human well-being, for example cleaner air and reduced climate change. The *benefit* is the socio-cultural or economical welfare gain provided through the ecosystem service, such as health, employment and income. Finally, actors in society can attach a *value* to these benefits. Value is most commonly defined as the contribution of ecosystem services to goals, objectives or conditions that are specified by a user (Costanza, 2000; Farber et al., 2002). The *value perception* can cause changes in policy and decision making, for instance when certain services or resources are not available or too expensive. Alternatively, value perception can influence the ecosystem service value, for instance through increasing demand for a certain product. *Policy and decision making* form preconditions, constraints and incentives for land management and *other drivers* (Daily et al., 2009; Fisher et al., 2009).

2.2. Indicator selection and evaluation

To operationalise the framework for indicator selection, it is important to select indicators that provide accurate information on all main aspects of ecosystem services provision: land management, ecosystem properties, function, and service (Fig. 1). To be able to evaluate the usefulness of indicators for our purpose, we compiled a set of criteria. First, we assembled general criteria for indicators, based on information from ecological assessments. We found that the selection process of indicators should be flexible and consistent, and that indicators should be comprehensive and understandable to multiple types of end users. A flexible, yet consistent selection process implies that multiple frameworks can be used, depending on the scope and aim of the assessment (Niemeijer and de Groot, 2008). A test for comprehensiveness evaluates whether the whole set of indicators would provide