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Review

How to analyse ecosystem services in landscapes—A systematic review

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ABSTRACT

Ecosystem services (ES) is a significant research topic with diverse modelling and mapping approaches. However, the variety of approaches—along with an inconsistent terminology—cause uncertainties concerning the choice of methods. This paper identifies and qualitatively assesses methods for mapping ES in terrestrial landscapes, based on a systematic review of the scientific literature. It further aims to clarify the associated terminology, in particular the concept of *landscape* and *landscape scale*. In total, 347 cases of ES mapping were identified in the reviewed papers. *Regulating and maintenance* services were most commonly mapped (165), followed by *cultural* (85), and *provisioning* services (73). For individual ES, a large variation in number of mapping cases was found. This variation may either reflect the perceived importance of the ES, or that different ES can be more or less easily mapped. Overall, *Logical models* and *Empirical models* were most commonly used, followed by *Extrapolation*, *Simulation/Process models*, *Data integration*, and *Direct mapping*. Only twelve percent of all ES mapping cases were validated with empirical data. The review revealed highly diverging views on the spatial extent of landscapes in studies of ES, and that the term landscape is sometimes used rather arbitrarily.

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1. Introduction

Ecosystems provide various goods (e.g. food and construction material) and services (e.g. regulation of water flows) to society, which contribute to our survival and well-being. Such "ecosystem services" (ES) (Daily, 1997; MEA, 2005) have been evident to humans throughout history, but not explicitly considered until the late 1960s and 1970s (Hermann et al., 2011; Portman 2013), when scientists began to address the societal value of nature's functions (King 1966; Helliwell 1969; Dee et al., 1973; Bormann and Likens 1979). The term "ecosystem services" was introduced in 1981 (Ehrlich and Ehrlich, 1981) and, following important contributions by, e.g., Daily (1997) and Costanza et al. (1997), the Millennium Ecosystem Assessment (MEA) (MEA, 2003) brought global attention to its importance. Today, the concept ES is recognised in policy and it is a significant research topic with diverse modelling and mapping approaches supporting studies at different spatial and temporal scales (Burkhard et al., 2013).

Mapping—the organization of spatially explicit quantitative information—is essential for many assessments of ES since both supply and demand can be spatially explicit (Troy and Wilson, 2006). Mapping can allow full assessment and quantification of ES (Crossman et al., 2013), including the spatial distance between providing areas and benefiting areas (Fisher et al., 2009; Bastian et al., 2012). Crossman et al. (2013) argue the need for better understanding of where ES are supplied so that "stocks of natural capital and the flow of ES can be monitored and managed across spatial and temporal scales". They also point out that spatially explicit understanding of conditions of, and threats to, natural capital, will facilitate that resources are allocated to where they are most needed. The usefulness of maps (i.e., spatial products from mapping) to support governance and management of ecosystems and their services is noted by Hauck et al. (2013). Many methods and tools exist to map and quantify ES, applicable for highly differing scales. This, along with inconsistencies in the terminology, creates uncertainties concerning the choice of methods. The inconsistent terminology can even cause uncertainty in what is actually being mapped (Crossman et al., 2013).

This paper identifies and qualitatively assesses methods for mapping ES in terrestrial landscapes, based on a systematic review of the scientific literature. It further aims to clarify the associated terminology, in particular the concept of *landscape* and *landscape scale*, based on a meta-review of recent literature and outcomes of the systematic review.

2. Material and methods

2.1. Meta review

In order to clarify the terminology used in studies of ES, in particular the concept of *landscape* and *landscape scale*, and to develop an assessment framework for the systematic review of methods, a meta-review of recent literature was performed. Review papers were identified from keyword searches in the Scopus and Web of Science databases. Additional papers were identified by examining the bibliographies in the review papers and papers that cite these. The outcome of this review is presented in Section 3 (Theory).

2.2. Systematic review

Papers included in two previous review publications (Crossman et al., 2013; Andrew et al., 2015) were reviewed on methods used for mapping ES at a landscape scale. These two review publications also cover papers previously reviewed by Egoh et al. (2012) and Martinez-Harms and Balvanera (2012). An additional literature search was carried out to identify relevant papers published after 2012. The full literature selection process is described in Table 1. The outcome of this review is presented in Section 4 (Results and Discussion).

The 1112 papers identified in the literature search were screened to determine if they met two relevance criteria: (1) spatially explicit results (i.e., maps) presented for at least one ES; and (2) study stated to be made at a landscape scale, for the purpose of landscape planning, or referring to a study area as a landscape or as containing landscapes. A total of 170 papers fulfilled these criteria.

2.2.1. Assessment framework

2.2.1.1. General information. The 170 papers were reviewed on: (a) their targeted scale: *global, continental, international, national, or sub-national*; (b) the country/countries in which the study was performed; and (c) the year the paper was published.

2.2.1.2. References to landscapes. The papers were then reviewed on whether or not specific areas (the study area or any other area) were referred to as *landscapes*. The size of such areas was noted to facilitate a discussion of the spatial extent of landscapes.

2.2.1.3. Limitations in resolution and method. The papers were then reviewed on the resolution at which the spatial results were presented. Papers using a resolution of approximately 1 km^2 or coarser were not further reviewed. In addition, papers mapping only the monetary value of ES using value transfer, i.e. assigning monetary values to areas without prior quantification of biophysical or other estimates to support the monetization, were also excluded from further review. A total of 49 papers were eliminated in this step.

2.2.1.4. Ecosystem services studied. The remaining 121 papers were then reviewed on which ES that were mapped. A modified version of CICES v4.3 classification system was used (see Fig. 4, cf. Table 2). In case several ES that fall under the same ES category were studied separately (e.g., biomass for food and energy, respectively) using the same or similar methods, they were counted as one ES. A total of 347 cases of ES mapping was identified.

2.2.1.5. Mapping methods used. [•]

- The papers were then reviewed on the type of method that was used to map each ES. A categorisation system similar to Andrew et al. (2015) was used, as follows:
- *Direct mapping* refers to methods where survey and census approaches provide complete spatial information of the distribution of an ES.
- *Empirical models* refer to models based on point-based measurements of ES. Values are then explained and consequently estimated elsewhere using, e.g., regression analysis.
- *Simulation and process models* attempt to simulate or model ecosystem processes to identify [changes in] ES values [given changes in ecosystem properties]. Such models require no measurements of ES except possibly for calibration and validation.
- *Logical models* map ES based on a set of indicators using decision rules.
- *Extrapolation* methods parameterize ecosystem properties (often land-cover classes) for their level of ES supply, based on aspatial summary values.
- *Data integration* methods synthesize pre-existing spatial products to generate ES maps, often with rule-based approaches.

The first four types roughly constitute *ecological production function methods*, i.e., estimating the level of ES provisioning at a particular location given the biotic and abiotic characteristics of that site. The latter two roughly constitute *benefit transfer methods*, i.e., estimating the value of ES provisioning in one context by adapt-