Forest Ecology and Management 427 (2018) 7–16

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Sources and types of uncertainties in the information on forest-related ecosystem services

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ARTICLE INFO

Keywords:
Forest inventory
Survey
Indicator
Mapping
Uncertainty
Value of information

ABSTRACT

The concept of ecosystem services has gained importance in the forest management and forest policy processes in recent years. Ensuring the sustainable provision of ecosystem services requires accurate information of the current provision and methods for predicting the impact of important drivers, such as changes in land cover and land use. In this review, we define the sources of uncertainties in forest-related ecosystem service assessments and discuss their importance to the usability of the information for different purposes. The uncertainties are due to e.g. variation in the selected indicators for the ecosystem services, lack of primary information on them, poor correlation with the data used for mapping the ecosystem services to larger scale and for predicting the impacts of human interventions. The uncertainties can be random or non-random and their assessment is often ignored, especially in the case of the non-random errors. As a result, different assessments and subsequent decision recommendations can be highly conflicting. We do not expect that the accuracies would significantly improve in the short term. The best way to proceed is therefore to assess the uncertainties and take them into account in the decision making for forest management.

1. Ecosystem services concept as a means to promote sustainable forest management

Ecosystem services (ES) represent the goods and services derived from the functions of ecosystems utilized by the humanity (Costanza et al., 1997, 2017; Crossman et al., 2013). The concept of ecosystem services was originally designed as an educational and communication tool (Daily, 1997) to acknowledge that human wellbeing is tightly connected to the provision of these services. Nowadays the concept of ecosystems services is the main framework for environmental policies and monitoring (Norgaard, 2010). The European Commission emphasizes the importance of accurate information on ecosystem services as the basis of the EU Biodiversity Strategy for 2020 (European Commission, 2011). Land use change is the most important driver affecting the ecosystems (Dong et al., 2015). As a result, ecosystem services have been emphasized in national and regional land use policies and planning (e.g. Frank et al., 2015, Haakana et al., 2017, Tammi et al., 2017). Policy makers are increasingly recognizing the potential of ecosystem service mapping in strategic planning (Vorstius and Spray, 2015).

In the cascade model (Fig. 1), the ecosystem services are addressed through the structure and process of the ecosystems and their functioning, benefits and value obtained from the used ecosystem services. The biophysical structures and processes create the basis for the functioning of the ecosystem and the functions create the capacity to provide services. The capacity to deliver a service exists independently of whether anyone wants or needs that service, but that capacity becomes a service only if a beneficiary can be clearly identified. The value of the benefit can be defined as economic, social, health or intrinsic value (Haines-Young and Potchin, 2010). The ecosystem services approach has been criticized, however, for taking a fully anthropocentric view and hiding the intrinsic values of nature (Fürst, 2015).

Ecosystem services can be grouped in many different ways (e.g. de Groot et al., 2002, MA, 2005; TEEB, 2010). In Common International Classification of Ecosystem Services (CICES), which is used in this review, the ecosystem services are divided to **provisioning**, **regulation and maintenance**, and **cultural** (Haines-Young and Potchin, 2010). Services that are most relevant from forest management point of view include provisioning services such as timber, berries and mushrooms, game, reindeer, and bioenergy; regulating and maintenance services such as climate regulation; and cultural services such as recreation and nature tourism. In the following text, we use the term 'ecosystem services' to refer to all possible forest-related ecosystem services in general and differentiate between them only when it is relevant from the point of view of data acquisition. In those cases, we always spell out the specific ecosystem services or steps of the cascade model (Fig. 1) we are

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https://doi.org/10.1016/j.foreco.2018.05.056
Received 2 March 2018; Received in revised form 24 April 2018; Accepted 24 May 2018

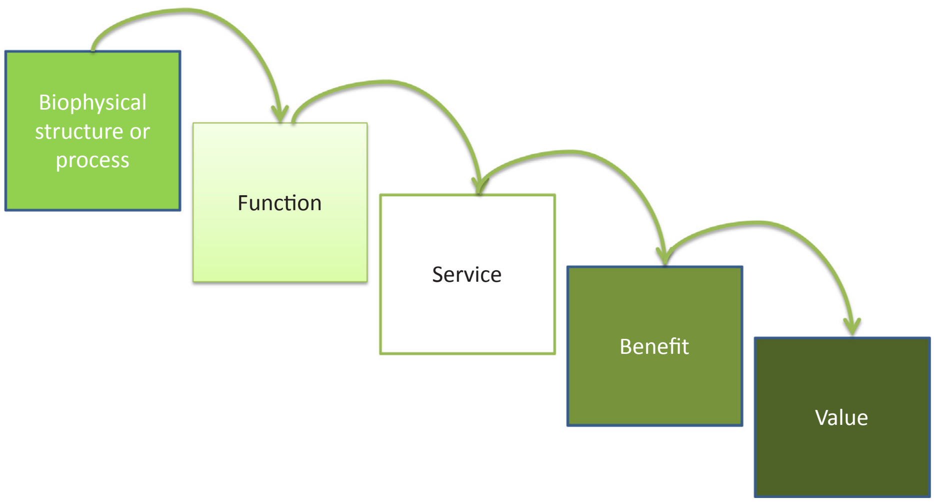

Fig. 1. The cascade model (modified from Haines-Young and Potchin, 2010).

referring to.

The ecosystem services are operationalized through a selected set of indicators (e.g. Müller and Burkhard, 2012). The purpose of the indicators is to support the management of ecosystems and to communicate on their condition. Thus, they simplify the complexity of the ecosystems to manageable concepts. The set of relevant ecosystem services and their indicators varies from region to another. For instance, Mononen et al. (2016) and Hansen and Malmaeus (2016) have presented a different set of indicators for Finland and Sweden, respectively, even though the two countries resemble each other very closely in terms of forest structure. This variation is one of the challenges when comparing international ecosystem service assessments (Maes et al., 2012b, Mononen et al., 2016). One possible reason for the variation is that the values of the experts who carry out the selection of the criteria implicitly reflect to the selection of the indicators (Menzel and Teng, 2010).

Sustainable management of natural resources can be seen as maximizing the social welfare obtainable from them (Kant and Lee, 2004). Sustainability means that the future generations can consume the ecosystem services to the same extent as the current one (e.g. Norgaard, 2010). Sustainable provision of ecosystem services thus requires a non-declining provision of all services over an infinite period in time. Only changes that are inarguably sustainable are Pareto improvements, where the supply of ecosystem services improves with respect to one or more indicators but does not deteriorate with respect to any of the other services. Trade-offs are inevitably related to all other changes in the current and future provision of the ecosystem services. The decision on whether such changes are sustainable or not depends on the values of the humans making the evaluation (e.g. Fürst et al., 2010, Vorstius and Spray, 2015, Hartikainen et al., 2016). Including ecosystem services into decision making is one way to strive for sustainable forest management (e.g. Martinez-Harms et al., 2015). According to Meyer and Schulz (2017), however, forests are currently underrepresented in the studies related to ecosystem services.

Ensuring that ecosystem services are provided sustainably requires information of the current state. Sample-based information is adequate to make decisions on sustainability at national and regional scales. For decision concerning locations, such as where it is important to protect, restore or improve ecosystems or their services, a map – i.e. spatially explicit information – is required. The maps can be used, for instance, to detect hotspots or coldspots, i.e. areas with high or low supply of ecosystem services (e.g. Pagella and Sinclair, 2014). Co-occurrence of different ecosystem services in an area implies synergies and tradeoffs (Maes et al., 2012a). The maps can also be used to detect areas where the supply of ecosystem services decreases or increases due to changes in land use (Pagella and Sinclair, 2014); to identify providing and benefiting areas (Syrbe and Waltz, 2012); and to communicate the effects of policies to the land use and ecosystem service provision (Vorstius and Spray, 2015).

Real policy decisions require two or more decision options to choose from and predictions of the future consequences of these options (Corona, 2016). To ensure sustainable provision of ecosystem services, information needs to be available and of sufficient quality. We also need to have decision support tools for predicting the future development of the services affected by the decisions executed.

We review the acquisition of primary data (Section 2) and mapping of ecosystem services (Section 3), concentrating on those services relevant from forest management point of view. We review the methodology available to assess the uncertainty in the ecosystem services data (Section 4) and note that in most cases uncertainty assessment is lacking or inadequate. The search of references was carried out using Web of science on 15 November 2016. We used one keyword describing the uncertainty assessment (e.g. “error” , “uncertainty”, “validation”, “evaluation”), one keyword describing the data collection and usage (e.g. “mapping”, “inventory”, “data acquisition”) and as the last keyword “ecosystem services”. While the inclusion of all resulting articles to this review is by no means exhaustive (Web of science gave 22 652 hits for the keyword “ecosystem services”), we specifically attempted to focus on articles that acknowledged uncertainties. Finally, we discuss our findings on the gap between the information demand and supply in terms of contents, scale, accuracy and uncertainty assessment with respect to decision making.

2. Acquiring ecosystem services data

2.1. Indicators for ecosystem services

The data acquisition for ecosystem services is operationalized through a set of indicators that can be assessed. Primary data are needed for the indicators of the structure, function, benefits, and value in the cascade model (Fig. 1). For instance, the habitat area (ha), production (kg/ha/A), yield (kg), and monetary value (€) could serve as the indicators of structure, function, benefits, and value, respectively, if forest berries and mushrooms were considered as an example service (Mononen et al., 2016).

Selecting a good set of indicators is important, as those vary in quality for decision making. Auvinen et al. (2007) evaluated indicators of biodiversity using several criteria: relevance, impact, effectiveness, cost-effectiveness, acceptability, incentive value, transparency and opportunities for participation, equity, flexibility, predictability, and