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Analysis of the uncertainty in the monetary valuation of ecosystem services — A case study at the river basin scale

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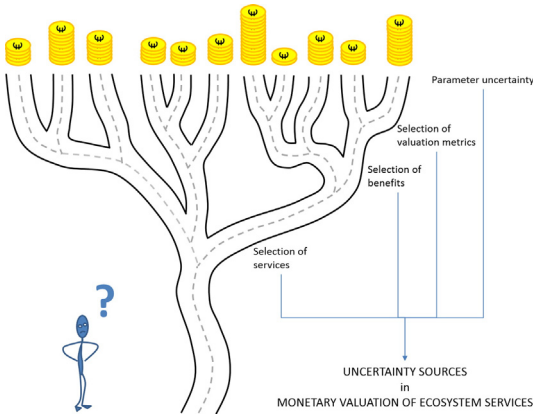
HIGHLIGHTS

- Uncertainty in monetary valuation of ecosystem services is not adequately defined.
- It is crucial to quantify and minimize uncertainty to avoid bias in decision making.
- Sources of uncertainty in monetary valuation of ecosystem services were quantified.
- The highest uncertainty was caused by the considered services and benefits.
- The parametric uncertainty was found less critical than the structural uncertainty.

GRAPHICAL ABSTRACT



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ABSTRACT

Ecosystem services provide multiple benefits to human wellbeing and are increasingly considered by policy-makers in environmental management. However, the uncertainty related with the monetary valuation of these benefits is not yet adequately defined or integrated by policy-makers. Given this background, our aim was to quantify different sources of uncertainty when performing monetary valuation of ecosystem services, in order to provide a series of guidelines to reduce them. With an example of 4 ecosystem services (i.e., water provisioning, waste treatment, erosion protection, and habitat for species) provided at the river basin scale, we quantified the uncertainty associated with the following sources: (1) the number of services considered, (2) the number of benefits considered for each service, (3) the valuation metrics (i.e. valuation methods) used to value benefits, and (4) the uncertainty of the parameters included in the valuation metrics. Results indicate that the highest uncertainty was caused by the number of services considered, as well as by the number of benefits considered for each service, whereas the parametric uncertainty was similar to the one related to the selection of valuation metric, thus suggesting that the parametric uncertainty, which is the only uncertainty type commonly considered, was less critical than the structural uncertainty, which is in turn mainly dependent on

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the decision-making context. Given the uncertainty associated to the valuation structure, special attention should be given to the selection of services, benefits and metrics according to a given context.

1. Introduction

Ecosystem services are the benefits we obtain from ecosystems, such as waste treatment by river ecosystems. These services are generated by ecosystem functions, and provide multiple benefits to human wellbeing (e.g. reduced water treatment costs, more opportunities for recreation due to a higher water quality), which in turn can be valued in either monetary or non-monetary units (de Groot et al., 2010). Specifically, the valuation of ecosystem services involves the quantification of the value of multiple benefits using the appropriate market and non-market valuation techniques, so that a value is assigned to each one of the benefits. Because of the lack of homogeneity in the non-monetary units, the values cannot be easily aggregated or compared. Thus, expressing the value of an ecosystem in monetary units appears to be useful, since this metric is meaningful to stakeholders (Costanza et al., 1997; Naidoo and Ricketts, 2006; Jordan et al., 2010). Furthermore, the lack of monetary valuations has been identified as one of the underlying causes for the observed degradation of ecosystems and the loss of biodiversity (TEEB, 2010).

Monetary valuations of the benefits associated with a given management action are often compared with the management action costs, thus performing cost-benefit analyses. In this context, small differences in the value of the quantified benefits might influence the decision on whether or not to perform a conservation management action (BenDor et al., 2011). Therefore, it is crucial to precisely quantify benefits of ecosystem services, and to assess and minimize uncertainty to avoid bias or even fault in decision making (Chavas, 2000; National Research Council, 2005; Naeem et al., 2015). The assessment of uncertainty in monetary valuations of ecosystem services is therefore crucial, but not a straightforward issue according to the literature (Turner et al., 2004; Carpenter et al., 2006; Nicholson et al., 2009; Johnson et al., 2012). According to these studies, there is a need to improve identification, quantification and communication of uncertainties in the monetary valuation of ecosystem services.

The uncertainty in ecosystem services monetary values rises from the uncertainty in the quantification of ecosystem services in biophysical units, as well as from the uncertainty in the quantification of the monetary values (TEEB, 2010). Because of these two large sources of uncertainty, the monetary values might contain outstanding degrees of uncertainty (Scolozzi et al., 2012). However, the uncertainty in ecosystem services valuation is commonly ignored, or only partly considered (Seppelt et al., 2011). Seppelt et al. (2011) reviewed 153 ecosystem service studies from current scientific publications, and found that 45% of them did not provide sufficient information regarding uncertainty in their results. Among those assessing uncertainty, most of them focused exclusively on the uncertainty in the quantification of ecosystem services in biophysical units (Johnson et al., 2012; Sánchez-Canales et al., 2012, 2015; Hou et al., 2013), despite the fact that socio-economic parameters used in the valuation process have been identified in some studies to be more relevant when quantifying the monetary values than biophysical parameters (Acuña et al., 2013). Furthermore, no clear guidelines exist on which aspects to consider when assessing uncertainty in the monetary valuation of ecosystem services (TEEB, 2010; Johnson et al., 2012; Hou et al., 2013). Some attempts have been made to define guidelines, and a recent study even assembled a template to identify where uncertainty might be greatest and suggested conducting sensitivity analyses to explore the effects of uncertainty on valuation estimates all along the pathway from action to change in the value of ecosystem services related to water quality (Keeler et al., 2012). Overall, there are two types of uncertainty in the monetary valuation of ecosystem services: the structural uncertainty and the parametric uncertainty.

Structural uncertainty arises from the structure of the valuation process (i.e., selection of services, benefits, and valuation metrics), whereas the parametric uncertainty arises from the uncertainty in the parameters used in each one of the valuation metrics (i.e. valuation methods). In regards to the structural uncertainty, the decisions on the number of services and benefits to consider, as well as on which valuation metric to use are commonly, but not always, driven by the study goal and are therefore dependent on the decision-making context. Regardless of the rationale behind the selection of services and benefits, several authors pointed out the complexity of aggregating all the benefits that an ecosystem can provide while avoiding double counting the value of the same service through different benefits with a certain overlap (Arrow et al., 2000; de Groot et al., 2002; Wallace, 2007; Mendelsohn and Olmstead, 2009; Spangenberg and Settele, 2010; Hou et al., 2013). Thus, the careful selection of ecosystem services and benefits is crucial if aiming to capture the different values an ecosystem can provide.

However, studies on ecosystem services commonly focus on too few ecosystem services, or on too few benefits per service (Acuña et al., 2013; Honey-Rosés et al., 2013). For instance, among coupled biophysical and economic models, the valuation section in the InVEST model is restricted to one or two benefit(s) per service (Tallis et al., 2011), thereby neglecting part of the monetary value of a given service, restricting the applicability of the model to certain contexts, and introducing uncertainty in the valuation. For example, the model on the ecosystem service water provisioning only considers the value of water provisioning for reservoir hydropower production (Terrado et al., 2014). Another component of the structural uncertainty relates to the choice of the valuation metric for a given benefit, as multiple valuation metrics could be applied. The choice of valuation metric has been reported to be relevant for the valuation, as different valuation metrics might be based on the same set of economic assumptions but approach the ecosystem services from different perspectives, with results varying widely depending on the choice of valuation metric rather than on the object under analysis (Spangenberg and Settele, 2010; Hou et al., 2013). For example, the application of two alternative valuation metrics to the same object of measurement (willingness to pay and willingness to accept) might result in different values (TEEB, 2010). Similarly, previous studies showed that different valuation metrics result in different rankings of nature-conservation value (Rouquette et al., 2009). Overall, structural uncertainty consists of decisions partly related with the context of the study, partly with data availability, and partly on practitioners' subjective decisions, all of them involving that the quantification of the monetary value of ecosystem services does not deliver a unique value, but context and method dependent value estimates (Spangenberg and Settele, 2010).

Parametric uncertainty relates to the uncertainty in the parameters included in the valuation metrics such as the market prices of agricultural products, which are subjected to wide swings in value due to shifts in preferences or environmental conditions (Johnson et al., 2012). Another key parameter subject to high uncertainty is the discount rate, which is used to weigh the sequence of costs and benefits over time (TEEB, 2010) and often leads to diverging long term valuation results (Ludwig et al., 2005; Carpenter et al., 2006). It is because of the uncertainty in these key parameters that parametric uncertainty has also been appointed to be critical for the valuation of ecosystem services (Woodward and Wui, 2001; Spangenberg and Settele, 2010; Keeler et al., 2012). Actually, most of the studies to date that have considered uncertainty in ecosystem services valuation focused exclusively on the