Ecosystem Services 21 (2016) 39–52

Contents lists available at ScienceDirect

Ecosystem Services

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

Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach

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ARTICLE INFO

Article history:
Received 10 September 2015
Received in revised form
6 July 2016
Accepted 19 July 2016
Available online 29 July 2016

Keywords:
Flood protection
Ecosystem service cascade
Replacement costs
Avoided damage costs
Valuation
Flood hazard map

ABSTRACT

We present a method for assessing the ecosystem service (ES) flood protection of riparian wetlands and apply it to a riparian forest in Germany. The suggested workflow implements a cascade approach to ES characterization in which current provisioning is assessed in four steps: (1) qualitative description of biophysical processes and structures, (2) definition and quantification of main and additional ecosystem functions, (3) qualitative description of economic and social benefits and (4) valuation. Future provisioning is addressed by identifying pressures and analyzing potential enhancements. Using flood hazard and risk maps produced in response to the EU floods directive, quantification of the ecosystem function water retention as well as monetary valuation by the replacement cost and avoided damage cost methods were achieved without site-specific hydrological-hydraulic modeling. Technical structures with the same water retention volume as the investigated ecosystem in case of an extreme flood would cost 68 million EUR (equivalent ES value EUR 1900/ha/yr). In case of a 10-year flood, the riparian forest avoids damage costs of at least 26 million EUR (EUR 4300/ha/yr). We provide suggestions for standardizing the application of both monetary valuation methods and discuss their information content as well approaches for non-monetary valuation of the ES flood protection.

1. Introduction

Reported flood damages have increased from about USD 7 billion per year world-wide in the 1980s to about USD 24 billion per year in 2011 (adjusted for inflation; Kundzewicz et al., 2014). Since 1970, the annual number of flood-related deaths has been in the thousands, with more than 95% in developing countries (Handmer et al., 2012). The main reason for increased losses is greater exposure of people and assets (Handmer et al., 2012; Kundzewicz et al., 2014). As heavy rainfall events are very likely to become more intense and frequent due to climate change, except in areas with strongly reduced total rainfall, floods are also expected to increase in the future in many areas of the world (Döll et al., 2015). Whether flooding occurs after a heavy rainfall or snowmelt event strongly depends on the natural characteristics of the drainage basin and the floodplain. While technical measures such as dykes or man-made reservoirs may serve as additional flood protection, the focus is put increasingly on flood protection by the ecosystem itself, in particular the floodplain ecosystem that can store floodwater and decrease downstream peak discharges (Damm et al., 2011; Scholz et al., 2012). Thus, protection of existing natural floodplain ecosystems or their restoration may be an appropriate strategy for flood protection and adaptation to climate change (e.g. BMU and BfN, 2009). Decision-making in favor of this type of flood protection is impacted by financially attractive alternative land uses including urban and agricultural uses.

Therefore, assessment of the ecosystem service (ES) *flood protection* as provided by natural floodplains, e.g. riparian forests or riparian wetlands, is essential for making well-grounded decisions. Such an assessment should demonstrate the value of a particular ecosystem for flood protection in downstream areas, ideally in both monetary and non-monetary terms. Not all the benefits that humans derive from ecosystems can or should be expressed in terms of money. However, expression of at least a part of the total ES value in monetary terms allows internalizing so-called externalities in economic accounting procedures (TEEB, 2010a). Please note that assessment of ES does not imply that ecosystems *only* have value for the services they provide to people, i.e. an instrumental value, or that non-human living beings do not have intrinsic rights and intrinsic value (Hunter et al., 2014; but see Goulder and Kennedy (1997)). The anthropocentric concept of ecosystem services may be recognized as a pragmatic approach in support of sustainable development also by those who share a biocentric (or another non-anthropocentric) worldview.

The challenge is that there is no blueprint or universal framework for ecosystem service assessments (ESA) (Haines-Young and

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http://dx.doi.org/10.1016/j.ecoser.2016.07.012
2212-0416/

Potschin, 2009; Seppelt et al., 2012). As is the case for other regulating ES, the value of the ES flood protection cannot be derived based on market prices. A specific challenge of this ES is that it is very site-specific, such that its valuation can hardly rely on existing studies for other locations. Of the 1310 monetary ES values collected by van der Ploeg and de Groot (2010), only 13 referred to flood protection by inland wetlands. Applied monetary valuation methods for ES flood protection are the calculation of replacement costs and avoided damage costs (Leschine et al., 1997; van der Ploeg and de Groot, 2010; Brander et al., 2013). In former studies, usually only one of the two methods was applied. Grygoruk et al. (2013) and Leschine et al. (1997), for example, calculated replacement costs, Kousky and Walls (2014) avoided damage costs. Other studies did some type of non-monetary valuation (e.g. Nedkov and Burkhard, 2012) or only investigated the ecosystem function leading to the ES (Posthumus et al., 2010).

There are a number of software tools for assessing ES (Peh et al., 2013). The Natural Capital Project provides the popular InVEST software which, however, does not include flood protection yet. An ESA software tool that covers the ES flood protection on a site scale is TESSA (Toolkit for Ecosystem Service Site-based Assessment). TESSA allows calculating avoided flood damage costs by wetlands but only if hydrological information on the impact of the wetland on inundated area during floods with a certain return period is available (Peh et al., 2013, 2014). This information needs to be derived by involved and costly hydrological-hydraulic modeling of climate and land cover-driven streamflow dynamics and inundation as affected by river and floodplain morphology.

With our study on the ES flood protection, we contributed to a project that aimed at assessing all important ES of the riparian forest Bulau located directly upstream of the city of Hanau in the Federal State of Hesse, Germany. Through the Bulau and the city runs the river Kinzig which inundates almost the whole riparian forest and parts of the city during large flood events. Due to the water storage capacity of the riparian forest, peak discharges of floods and therefore inundation of Hanau are reduced as compared to other land uses.

To assess the ES flood protection in a comprehensive manner, we developed a workflow that allows implementing the cascade approach of de Groot et al. (2010), Haines-Young and Potschin (2010) and TEEB (2010a). The assessment includes the consideration of the current state of the ES with its biophysical processes and structures, the definition and quantification of an ecosystem function, the detailed description of the resulting benefits and the valuation of the ES. Both replacement costs and avoided damage costs were computed on the basis of easily available data and without site-specific hydrological-hydraulic modeling. The future ES provisioning was addressed by discussing pressures on the ecosystem and potential enhancements of ES provisioning (Haines-Young and Potschin, 2009; MA, 2005a; Rounsevell et al., 2010; TEEB, 2010a).

In this paper we present a structured and comprehensive approach for assessing the ES flood protection of a riparian wetland. To support the development of standards of valuing the ES flood protection, we clarify various aspects that affect monetary valuation and discuss how complementary non-monetary valuation may be approached. In addition, we wish to promote the comparability of ESAs, and therefore summarize our assessment using the Purpose, Scope, Analysis, Recommendations, and Monitoring (PSARM) Blueprint by Seppelt et al. (2012) (see Appendix).

2. Methods

2.1. Workflow for assessing ES

Fig. 1 shows the workflow we applied for assessing the ES flood protection, based on a cascade approach. The workflow includes four steps for assessing the current provisioning of an ES and two regarding its future provisioning. Assessment of the current state of an ES starts with the qualitative description of the biophysical structures and processes of the ecosystem that are related to ES provisioning. Then a *“subset of ecosystem processes and components that is directly involved in providing the service”* is defined as an ecosystem function (TEEB, 2010a: 15, their Fig. 5). In this study, we quantified relevant indicators of the ecosystem functions (Fig. 1). The next step of the ESA is a detailed qualitative description of the economic and social benefits of the ES to the society. A benefit is defined as *“the positive change in wellbeing from the fulfillment of needs and wants”* (TEEB, 2014). In contrast to the TEEB cascade, we do not include *“ecological (sustainability)”* benefits (TEEB 2010a: 15, their Fig. 5) but rather add a second phase to the workflow in which the future provisioning of the ES is considered. Following the description of the benefits, i.e. the increase of human wellbeing due to the ecosystem, the value of the ES is characterized. This is done by assessing the importance of the ES for human wellbeing, expressing the importance either in monetary or in non-monetary terms. In our case study, ES was valued monetarily by two alternative methods, the replacement cost and the avoided damage costs method. Non-monetary valuation was not done but approaches for its application for the ES flood protection are discussed. Finally, future provisioning of the ES is assessed. We identified (1) pressures that may negatively affect ES provisioning and (2) options for enhancing ES provisioning (Fig. 1 bottom) (Haines-Young and Potschin, 2009; MA, 2005a; Rounsevell et al., 2010; TEEB, 2010a). In other cases, modeling of the impact of future pressures and enhancement measures on the four elements of the workflow (Fig. 1 top) may be useful.

The first four steps of the workflow (Fig. 1 top) are also elements of the cascade models of Haines-Young and Potschin (2010) and TEEB (2010a). But those cascades show “ecosystem services” as an additional element between “ecosystem functions” and “economic and social benefits”. Cascade models clarify that ecosystem functions become ES (only) if humans exist who may enjoy the benefits generated by ecosystem functions; putting “ecosystem services” between “ecosystem functions” and “benefits” illustrates that ES are derived from ecosystem functions and lead to benefits for humans. However, cascade models may not be interpreted as a workflow for assessing an ES. ES are defined as the benefits that humans derive from ecosystems (MA, 2005a). Therefore, when assessing ES one cannot, as the cascade models may suggest, first characterize the ES and then the benefits as these are per definition the same. Instead, as shown in Fig. 1 (top), it is the joint description of (1) biophysical structures and processes, (2) ecosystem functions, (3) the benefits derived from the ecosystem function and (4) the value of the benefits that make up the characterization of an ES.

2.2. Data

Quantitative calculations carried out in this study were based on easily accessible data. Central to this study were flood hazard maps for Hanau including the riparian forest Bulau. The maps were produced in response to the EU Floods Directive (EU, 2007), a European-wide effort to improve flood protection. This regulatory framework prescribes the assessment of flood risks in all 27 member states of the EU (Müller, 2010). Flood hazard maps show flooded areas and inundation heights for statistical flood events with different return periods and thus magnitude. Additional flood risk maps indicate the