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An ecological economic assessment of flow regimes in a hydropower dominated river basin: The case of the lower Zambezi River, Mozambique

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HIGHLIGHTS

- Presents a holistic tool for ecological economic assessment of alternative flow regimes
- Re-operating dams can increase the total economic value of a river basin.
- Dam re-operation may benefit ecosystem more than negatively affecting hydropower.

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ABSTRACT

The flow regime of rivers, being an integral part of aquatic ecosystems, provides many important services benefiting humans in catchments. Past water resource developments characterized by river embankments and dams, however, were often dominated by one (or few) economic use(s) of water. This results in a dramatically changed flow regime negatively affecting the provision of other ecosystem services sustained by the river flow. This study is intended to demonstrate the value of alternative flow regimes in a river that is highly modified by the presence of large hydropower dams and reservoirs, explicitly accounting for a broad range of flow-dependent ecosystem services. In this study, we propose a holistic approach for conducting an ecological economic assessment of a river's flow regime. This integrates recent advances in the conceptualization and classification of ecosystem services (UK NEA, 2011) with the flow regime evaluation technique developed by Korsgaard (2006). This integrated approach allows for a systematic comparison of the economic values of alternative flow regimes, including those that are considered beneficial for aquatic ecosystems. As an illustration, we applied this combined approach to the Lower Zambezi Basin, Mozambique. Empirical analysis shows that even though re-operating dams to create environmentally friendly flow regimes reduces hydropower benefits, the gains to goods derived from the aquatic ecosystem may offset the forgone hydropower benefits, thereby increasing the total economic value of river flow to society. The proposed integrated flow assessment approach can be a useful tool for welfare-improving decision-making in managing river basins.

1. Introduction

Many river basins have been developed with a view to maximizing certain water uses, for example irrigated agriculture or electricity generation, which often required the construction and operation of large reservoirs. Such developments inevitably modified the natural flow regime, often to such an extent that other uses of water were severely constrained. Fisheries and the functioning of aquatic ecosystems are typical examples that have suffered from changes in flow regime. Concerns for these negative impacts of water resources developments in river basins have given rise to the concept of "environmental flow".

The aim of environmental flow is to protect, maintain or restore to a certain degree related environmental services. A number of methods have been developed in the past 15 years to identify environmental flow requirements (e.g. King and Louw, 1998; Dyson et al., 2003; Hughes and Hannart, 2003; Acreman and Dunbar, 2004; Hirji and Davis, 2009; Poff et al., 2010; King and Brown, 2010; McClain et al., 2013; Olsen et al., 2013). While a plethora of studies have been attempting to set the standard for environmental flows, there has been a reluctance to implement such flows. Here we identify two

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major challenges that are associated with the lack of willingness or motivation to implement environmental flows: the first is related to valuation, and the second to flow regimes.

1.1. Valuation

Instituting and enforcing environmental flows tend to negatively impact established (economic) uses of water, especially in closing and closed basins. Such established economic costs (or benefits forgone) are relatively easier to define, and hence easily inform arguments against environmental flows. In contrast, other ecosystem services that a river basin can potentially provide (but which have been impaired by established economic uses) are often much harder to quantify and value. Moreover, there are few debates regarding valuation studies and cost–benefit analyses conducted with attempts to incorporate the intrinsic value of nature. This debate has been related to the possible exaggeration of environmental costs of established uses and/or the benefits of ecosystem services. Therefore those studies were not taken seriously and ignored to a large extent by decision-makers (Braat and De Groot, 2012; Chee, 2004; De Groot et al., 2010). There is a general lack of trust in valuation methods, and this is problematic "…because it is impossible to manage what we do not value" (Salles, 2011).

1.2. Flow regimes

Ecosystem goods or services need to be linked quantitatively to river flows. This is not very problematic for certain goods or services. For example, the amount of irrigation water a certain crop under a certain climate requires and the increase in crop yield with one additional unit of water can be easily calculated. Similarly quantifiable is the amount of electricity that can be produced by one unit of water in a given reservoir at a certain water head. For other goods, such as fisheries, flood protection or tourism, it is difficult to establish a quantitative link with river flows. For some of these goods, a minimum flow in different parts of a river system may be required. However, this may not be sufficient to lead to the restoration of natural environmental processes on which, say, tourism may rely. These goods may require a flow regime that is not constant, but changing over time, both intra-annual (dry and wet seasons) and inter-annual (small and large annual droughts and floods) (Korsgaard, 2006; Korsgaard et al., 2008).

In this study, we propose a holistic, integrated approach for developing an economic assessment of alternative river flow regimes to aid in decision making. This approach draws on the concept of ecosystem services developed by the United Nations (UN) millennium report, and adopts a framework for valuation used by the United Kingdom National Assessment Report (UK NEA) of 2011, which has made important conceptual improvements on how the goods or services and the value that ecosystems generate for people can be quantified. Our approach further integrates the ecosystem valuation framework with the flow assessment technique developed by Korsgaard (2006) and Korsgaard et al. (2008).

They use "service suitability curves" and "service provision indices" that incorporate information about the suitability of a flow regime for a given "good", allowing for a quantitative economic assessment of flow regimes. This integrated approach can show how the final goods are linked to ecosystem processes and services and how their value changes as one of their essential requirements (flows) are shifted. By combining the two novel methods (innovations in valuation of ecosystem goods and linking such goods and values to flow regimes), this paper develops a rigorous approach for comparing alternative flow regimes that incorporate environmental concerns.

We apply this approach to the Lower Zambezi River in Mozambique, in an attempt to assess the variations in economic value for maintaining different flow regimes. It is an appropriate case, as the Zambezi River has a severely modified flow regime due to two large reservoirs built on the main stream and numerous other reservoirs in tributaries. In addition the river also supports the economically important fisheries sector and a "Wetland of International Importance" under the Ramsar Convention in its delta (see e.g. Beilfuss (2010); Ronco et al. (2010); Tilmant et al. (2010)).

The structure of the remainder of this paper is as follows. The next section (Section 2) discusses conceptual and methodological considerations, focusing on the conceptualization of ecosystem goods, their valuation and their link to river flows. Section 3 briefly introduces the case study area, the Lower Zambezi, and the scenarios for alternative flow regimes. Section 4 presents the results and findings, starting with the identification of the five ecosystem goods considered, followed by the calculation of their economic value for the reference year of 2010 and their suitability curves and finally the total economic values of the different scenarios are calculated. Section 5 discusses the findings, conclusion and further considerations.

2. Conceptual and methodological considerations

2.1. From ecosystem services to ecosystem goods

The concept of ecosystem services has existed since the late 1970s and was introduced to describe public benefits that were provided by ecosystems (Braat and De Groot, 2012; Nahlik et al., 2012). As research on this subject proliferated, so did the consequent explanation of what constituted nature's services. Since then many definitions have been proposed (Table 1) and these are still being debated (Fisher et al., 2009). This debate is due to; how the scale of assessment, end user, and ecosystem are defined or classified (Bagstad et al., 2013; Fisher et al., 2009; Haines-Young and Potschin, 2010). Some have suggested that the diversity of definitions and classifications when looked at within a coherent framework, is actually beneficial as it allows us to match our approach to the ecosystem to be assessed based on the usefulness and purpose (Braat and De Groot, 2012; Fisher et al., 2009; Johnston and Russell, 2011). Fisher et al. (2009) go further to say that "…a single or fundamental classification system should be approached with caution".

The abundance of definitions is matched with the large number of frameworks to classify ecosystems. A few studies have also provided useful information for comparative assessment (see Fisher et al. (2009); Haines-Young and Potschin (2010); Lamarque et al. (2011); and Ojea et al. (2012)). Here we give a succinct overview of the different ways in which the authors have operationalized ecosystem services.

Table 1
Major definitions of ecosystem services (adapted from Braat and De Groot (2012); Nahlik et al. (2012)).

Definition of ecosystem services	Source
"The benefits human populations derive, directly or indirectly, from ecosystem functions"	Costanza et al. (1997)
"The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life."	Daily (1997)
"The capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly"	De Groot et al. (2002)
"The benefits people obtain from ecosystems"	MA (2005)
"Components of nature, directly enjoyed, consumed, or used to yield human well-being"	Boyd and Banzhaf (2007)
"The aspects of ecosystems utilized (actively or passively) to produce human well-being"	Fisher et al. (2009)
"Ecosystem Services are the direct and indirect contributions of ecosystems to human wellbeing."	Kumar (2010)
"Ecosystem services are the outputs of ecosystems from which people derive benefits."	UK NEA (2011)