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Managing forest ecosystem services for hydropower production

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ABSTRACT

In many countries, hydropower development is rapidly becoming a focus of green growth policies. This represents a significant opportunity for ecosystem services-based land management that integrates environmental and development goals to benefit the hydropower sector and support economic growth. In this study, we present an approach for targeting ecosystem-provision investment in hydropower catchments coupled with hydrologic modeling to quantify the benefits of soil and water conservation activities. We demonstrate the application of this approach in five hydropower facility catchments in the state of Himachal Pradesh, India. The results show that there is a high potential for targeted soil and water conservation to increase sediment retention services that benefit hydropower facilities (up to a 44% reduction in sediment transported from uplands into streams), although this benefit is distributed non-uniformly across catchments and levels of investment. The extent to which services can be improved is strongly driven by current land use and management practices that impact how and where conservation activities can be located. Iterative use of the method described here, in a process of stakeholder engagement and capacity-building, enables policy makers to determine the optimal mix of land management strategies and budget allocation to maximize service improvements that support hydropower production.

1. Introduction

An increasing number of policies and programs in countries around the globe are turning to Payments for Ecosystem Services (PES) as a mechanism to link environmental and development goals (Bennett and Carroll, 2014). However, many of these programs are based on weak scientific foundations, in terms of understanding exactly how land management interventions undertaken by service "providers" can deliver specific benefits to service "users" (Naeem et al., 2015). There is an urgent need for science to fill this gap, to help these programs move from conceptual frameworks to credible and replicable methodologies that allow for designing and implementing effective ecosystem service-based policies (Daily and Matson, 2008).

As one example, the state government of Himachal Pradesh (HP) in northern India has recently adopted a PES policy around ecosystem services (ES) provision to support green growth (Government of Himachal Pradesh, 2013). In addition to this PES policy, a state hydropower development policy has mandated that hydropower projects invest at least 2.5% of the facility's cost in Catchment Area Treatment (CAT), with additional sub-targets including Payments for Ecosystem Service approaches (10% of CAT budget; Government of Himachal Pradesh, 2013).

This Himalayan state is rich in forest wealth, and hydropower and tourism sectors are the key drivers of economic growth. Both sectors depend on ES from forests: water regulation and soil retention services, for example, are important for the hydropower sector since electricity production decreases with lower flow rates or high sediment concentration in streams. Cultural and recreational services from forests are also important for the tourism sector. However, ES are threatened because of the ongoing degradation of forests and excessive soil erosion, driven by the growth of poorly planned settlements and associated over-exploitation for timber, fuelwood and other products, overgrazing, and poor agricultural practices on steep slopes (DEST, 2007).

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In Himachal Pradesh, India, as well as in other emerging economies around the globe with a similar dependence on hydropower development, it is clear that this is a key sector where land management policies can support development goals by greatly increasing the value of ES provided by landscapes (Guo et al., 2000; Guo et al., 2007). There is a growing need for practical solutions to help identify the specific places and land use practices that contribute the highest ES to the hydropower sector, in order to design effective PES schemes (Daily and Matson, 2008; Naeem et al., 2015).

While several government departments in HP – including forestry, rural development, and agriculture – are implementing soil and water conservation practices to improve the condition of watersheds, the focus of soil and water conservation activities to date has been primarily to improve conditions at the site scale, with the goal of reducing overall erosion and thereby sedimentation into streams (*e.g.*,NERIL, 2011). Thus far, attention has not been given explicitly to ES in order to connect the improvements at activity sites with watershed-scale goals for soil and water conservation, due in part to a lack of physical and monetary information on services and their beneficiaries. There is a risk of missing important opportunities to enhance public goods or reduce negative externalities due to this site-level focus and lack of landscape-scale attention to ES flows.

In this paper, we aim to fill this gap by (1) synthesizing the literature on catchment ES as it relates to diversion hydropower, (2) developing an approach for targeting land management with the explicit goal of improving or maintaining ES to hydropower facilities, and (3) illustrating this approach in a selection of diversion hydropower facilities in northern India. Our method uses spatially-explicit impact evaluation to target different locations for and levels of investment in soil and water conservation activities within hydropower catchment areas. We use hydrologic modeling to estimate impacts on ES delivery to downstream facilities, demonstrating this approach for five hydropower catchments in HP. The approach was applied in an iterative process of stakeholder engagement, which has increased the uptake of ES information in multiple policy contexts (Rosenthal et al., 2014; Ruckelshaus et al., 2015).

Our analysis contributes a replicable methodology for designing scenarios of conservation activities that will ensure optimal ES returns to hydropower, and evaluating the degree to which site-level activity impacts can scale up to changes in services delivered downstream. The work presented here differs from traditional environmental studies on hydropower that have focused primarily on the impacts of hydropower facilities and their management on downstream environmental resources (such as fish populations); instead, we focus on how soil and water conservation upstream of hydropower production can improve it and promote sustainable resource use in the process.

2. Ecosystem services and hydropower

Diversion ("run-of-the-river") hydropower facilities include minimal on-site water storage and are the simplest type of hydropower infrastructure. These facilities make up most of the hydropower in HP. The extent to which forests provide services that benefit hydropower facilities depends in large part upon the type and configuration of ecosystems in the upstream watershed (Brauman et al., 2007; Postel and Thompson 2005). Managing the landscape with a focus on ES flows can also lead to sustainable resource use, biodiversity and other co-benefits (Postel and Thompson 2005).

Previous studies have pointed to a need to understand watershed responses to management changes (Daily et al., 2009; Mendoza et al., 2011) and to develop models to quantify the economic value of these actions for hydropower production (Kareiva et al., 2011; Mendoza et al., 2011); however, few studies have assessed ES that specifically benefit diversion hydropower facilities based on spatially-explicit scenarios of upstream land management. Some researchers have incorporated an ES approach to the study of hydropower production, often focusing on the impact of reservoir operations on a suite of ES (Jager and Smith 2008; Hurford and Harou 2014) or on the identification of areas with high provisioning of service. For example, Guo et al. (2000, 2007) assessed the multi-year water balance in Yangtze watersheds based on the percentages of different land use types, but did not consider intra-annual variations or the spatial structure of land use. Researchers have used the InVEST model (Sharp et al., 2014) to examine the location (Bangash et al., 2013; Fu et al., 2014; Terrado et al., 2014) or amount (Bai et al., 2013) of water yield ES for reservoir hydropower at an average annual scale. Other studies have looked at sediment reduction ES (Bangash et al., 2013) in the context of total annual loads.

All of these studies have examined only the ecosystem service impact of pre-defined policy options, rather than using ES estimates to guide targeted investment in watershed services. In the following sections, we propose an approach to address this gap and provide an application example.

3. Proposed approach

Actively managing land use and forest cover to maximize hydropower production and minimize production costs is a key area where an ES approach can prove useful in developing management strategies and policies. In our study, we focused on understanding where, and in what activities, managers can invest to maximize improvement in watershed services (annual water yield and sediment retained). Throughout this manuscript, we use the term scenario to represent a combination of spatially-explicit land use maps – representing a possible reconfiguration of the landscape – along with the change in policy and/or drivers that led this scenario to vary from the baseline conditions. In our case study, scenarios represent different levels of investment in and locations for soil and water conservation activities in the catchments of several key hydropower facilities.

We applied the Resource Investment Optimization System (RIOS; Vogl et al., 2013) tool, developed by the Natural Capital Project and The Nature Conservancy, to five hydropower catchments in HP to produce scenarios of future landscapes, representing different priority locations for management interventions across a range of budgets. RIOS combines information on biophysical conditions and landscape context that can impact the effectiveness of watershed conservation activities (e.g. climate, soils, land use, and topography), social information describing feasible land management interventions, stakeholder preferences for undertaking those activities, and economic data on their costs. The outputs of the RIOS model are maps of the locations of soil and water conservation activities that provide the greatest ecosystem service returns towards multiple objectives.

The InVEST annual water yield and sediment models were then used to estimate the potential impacts of the RIOS-designed portfolios for services relevant to hydropower production (Sharp et al., 2014). These models quantify the change in services from a baseline condition to various scenarios of land use and management, predicting the integrated catchment response based on large-scale (in both space and time) catchment characteristics and processes. See Supplementary material for full details on the RIOS and InVEST model applications, parameterization, and testing.

We chose annual mean water yield and sediment export to indicate the level of ecosystem improvement possible with targeted soil and water conservation efforts, because these are