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Opportunity cost of water allocation to afforestation rather than conservation of natural vegetation in China

Junze Zhang[a], Tingyang Zhao[b], Chenchao Jiang[b], Shixiong Cao[b,*]

[a] School of Geography, Beijing Normal University, No. 19, Xinjiekouwai Street, Haidian District, Beijing 100875, PR China
[b] College of Economics and Management, Beijing Forestry University, No. 35, Qinhuadong Road, Haidian District, Beijing 100083, PR China

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ABSTRACT

Estimation of ecosystem service values is a hot area of research in ecological conservation and economics. However, the costs of these outputs are largely unknown. In this paper, we estimated the opportunity cost of water allocated to afforestation projects through mathematical modeling based on statistical data for all of China to provide support for restoration planning based on a fuller consideration of the true costs. To guide future ecological conservation and environmental policy development, we illustrate a neglected concept (ecosystem service costs) and use this concept to compare the ecological services provided by ecological restoration based on afforestation with those of restoration based on the conservation of natural vegetation using data obtained since 1949 in China. The results showed that afforestation and natural vegetation create annual costs related to use of the available water resources equal to 4800 and 3700 RMB ha^{-1}, respectively, representing a water opportunity cost of 1100 RMB ha^{-1} for afforestation. This illustrates the rule that "there is no free lunch" for any service, including ecosystem services. Therefore, to support the development of more effective and sustainable environmental restoration policy, it will be necessary to evaluate the associated opportunity costs.

1. Introduction

Ecosystem services are a primary environmental contribution that supports sustainable development of human society. These services directly support agricultural and industrial activity and human livelihoods, and indirectly support the sustainability of global socioeconomic development (Costanza et al., 1997; Lawler et al., 2014). To conserve and maintain the value of the services provided by an ecosystem, environmental managers around the world have attempted to restore healthy vegetation communities (Sivakumar, 2007). This is particularly true where unsustainable harvesting of forests and unsustainable grazing of grasslands have degraded ecosystems, leading to severe negative consequences such as erosion of unprotected soils by wind and running water, often leading to desertification. Because forests are known to protect soils and conserve water, many solutions to these problems have been based on afforestation (Wang et al., 2011a,b). Because of the magnitude of its environmental problems, China has undertaken the world's most extensive afforestation program (Li, 2004; Cao et al., 2011). From 1949 to 2011, 32.3% of China (nearly 3.1×10^6 km^2) was afforested to meet the forest industry's wood-supply needs, protect and nurture ecosystems, and conserve regional water resources, among other goals (State Forestry Administration, 1960–2012). However, in China and elsewhere, few planners have considered the costs associated with such programs that are intended to sustain ecosystem services; they have not assessed the costs of maintaining, managing, and utilizing the resources and services provided by the ecosystems they manage (Birch et al., 2010; Gao et al., 2013). Moreover, planners typically do not measure the detrimental environmental impacts of the restoration practices (Tilman et al., 2002). Such costs may be significant, and raise questions about the sustainability of current practices.

Restoration initiatives being undertaken around the world contribute significantly to sustainable development and are of major importance for adaptation to climate change (Birch et al., 2010). However, the models used to value ecosystem services ignore the associated costs, and assume that utilization of the services is free. Many early assessments focused only on estimating benefits, an approach that could potentially mislead decision-makers when the costs are significant (Naidoo and Ricketts, 2006). If society is to maximize the net benefits of environmental conservation, while avoiding undesirable consequences, there must be a fuller accounting of both the costs and the benefits of alternative programs, and such an accounting must become the basis for policy devel-

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* Corresponding author. Fax: +86 10 62337674.
E-mail address: shixiongcao@126.com (S. Cao).

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opment, environmental ethics, and management actions (Tilman et al., 2002). However, large-scale ecological restoration and conservation has complex and poorly understood consequences for the inputs and outputs of future natural and socioeconomic ecosystems, making estimation of the values of these ecosystem services difficult and inaccurate. It is thus necessary for the international science and policy communities to examine the extent to which conservation activities really improve ecosystem service values when all costs are accounted for.

2. Hypothesis

There is no such thing as a “free lunch”. Thus, there must inevitably be a cost associated with the provision of ecosystem services for humans. Therefore, when we estimate the value of ecosystem services, their costs should be not ignored. These costs are potentially huge, as they include the direct investments in ecological restoration and management, the opportunity costs of employing funds and ecosystem resources in this way, and other costs such as the risks created by ecological conservation activities.

In our review of the literature, we found few published studies (Costanza et al., 1997; Maler et al., 2008; Birch et al., 2010; Lawler et al., 2014) in which researchers paid attention to the consequences of the balance between the costs and the values of ecosystem services during landscape-scale ecological restoration, even though the importance of this balance for sustaining ecosystem health and socioeconomic development has been well covered in the ecological management literature. This can lead to problems when managers ignore constraints related to the regional climatic, pedological, hydrological, and landscape characteristics that would make a site unsuitable for a given type of restoration (Li, 2004; Cao et al., 2011).

To understand the impact of ecosystem service costs on an ecosystem’s management and guide future land change planning and the development of environmental policy, we studied China’s large-scale afforestation program. We used data from this program to calculate the water opportunity costs that arise from utilization of China’s limited water resources. Specifically, we compared these costs for two alternative approaches: restoration via afforestation versus restoration based on the conservation of natural vegetation. To support this comparison, we supplied seven previously published evapotranspiration models with data on the area of man-made forests obtained from China’s annual forestry yearbooks (State Forestry Administration, 1960–2012) and from China’s 7th national forest resource inventory bulletin (State Forestry Administration, 2009). We hope that our research will guide scientists, managers, and policy-makers to pay more attention to all costs in their research.

3. Methods

We obtained data on the area of afforestation in China in each Chinese province including provincial-level cities from 1952 to 2011 using China’s annual forestry statistical yearbooks (State Forestry Administration, 1960–2012). We defined the water opportunity cost by comparing water consumption by the surviving trees with consumption by a comparable area of the potential natural vegetation that would exist in each afforested area. We assumed that stable natural vegetation, mostly grassland or steppe vegetation with little economic value because of its state of degradation, would not be converted to forest. We also assumed that natural vegetation could survive in a dynamic equilibrium with the regional precipitation, since this vegetation had persisted for millennia under local conditions before human impacts became unsustainable; water consumption by this vegetation therefore provided a baseline against which alternatives such as afforestation could be compared. In addition, there is considerable evidence that if degraded natural vegetation in China is protected against additional degradation (e.g., by preventing grazing by livestock, by eliminating agriculture where the land cannot sustain intensive management), it will recover (Li et al., 2011).

We divided China into eight regions based on their annual precipitation and their temperature regime: the arid North, semi-arid North China Plain, semi-arid Loess Plateau Region, cold and semi-humid Northeast, cold and high-altitude Tibetan Plateau, semi-humid Southwest, warm and semi-humid Central region, and warm and humid South.

We used evapotranspiration (ET) to represent water consumption by forests and natural vegetation using seven previously developed evapotranspiration models. The data used as inputs for these models was obtained at a provincial scale, since higher-resolution data is not currently available, and we aggregated the data at a regional scale. All seven models were previously tested by Chen et al. (2014) to confirm their ability to reliably estimate ET under Chinese conditions (Cao and Zhang, 2015). Because we lacked sufficient data to parameterize each model for Chinese conditions and lacked sufficient ground-truthing data (e.g., field measurements of ET) to assess the accuracy of each model in each province and each aggregate region, it was not possible to choose a single model to represent all of China. Instead, we chose to use the average of the outputs from the seven models to represent water consumption by forests and by the natural vegetation they replaced. An additional simplification was necessary: since we could not find reliable data for all of China on the balance between runoff of precipitation into bodies of water versus infiltration and recharge of groundwater, or on differences between forests and native vegetation in terms of this balance, we did not attempt to account for this balance. Where our modeling approach will be used to directly support ecological restoration planning, planners should attempt to obtain site-specific data on this balance to improve their calculation of the actual water balance.

Because Chinese afforestation has most often been conducted in natural grasslands, we modeled ET by grasslands to represent water consumption by natural vegetation. The difference in ET between forests and grasslands represented the potential decrease in water consumption if ecological restoration had focused on preserving and improving the natural vegetation rather than replacing it with forest. This difference therefore represented the opportunity cost of the afforestation program.

To estimate these costs, we assumed that the additional water consumed by forests could be used for other purposes. We calculated the opportunity cost using the following equation:

$$(1)C_{itm}=\Sigma ET_{im}\times A_{it}\times R_{it}\times V_{it}$$

where C_{itm} (RMB) is the cost caused by a given restoration strategy (here, afforestation versus conservation of natural vegetation) in province i in year t that was predicted by model m; ET_{im} (m^3) is the evapotranspiration caused by afforestation or conservation of natural vegetation in province i that was predicted by model m; A_{it} (ha) is the afforestation area in province i in year t; R_{it} (%) is the tree survival rate in province i in year t (State Forestry Administration, 2009); and V_{it} (RMB m^{-3}) is the cost per unit of water in province i in year t.

Because prices increase with increasing scarcity of a resource, we assumed that the cost of water should increase with decreasing precipitation (i.e., increasing water scarcity) in a given region. To estimate the different costs, we used the following equation:

$$(2)V_{it}=b-aP_{it}$$