CrossMark

Spatially explicit return on investment to private forest conservation for water purification in Indiana, USA

Yangyang Wang [a,*], Shady Atallah [b], Guofan Shao [a]

[a] Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN, USA
[b] Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH, USA

ABSTRACT

Conservation programs that incentivize the increased provision of ecosystem services on private lands have become common policy instruments. The forgone revenues implied by these programs and the ecosystem services benefits they provide might be spatially heterogeneous. However, such programs are not always spatially targeted to maximize the return on conservation investment (ROI). Here, we use an integrated spatial, ecological-economic modeling approach to assess the ROI for water purification in the case of the Indiana Classified Forest and Wildlands (CFW) Program, United States. We compared the ROI of the existing non-spatially targeted CFW expansion to hypothetical, spatially targeted expansion scenarios in the White River Basin of Indiana. First, we projected nutrient retention services to increase greatly under the hypothetical spatially targeted scenarios and modestly in the non-spatially targeted, baseline case. Second, our results revealed the inclusion of conservation costs could substantially change the conservation priorities. In particular, private forestlands in subwatersheds with average conservation benefits and low conservation costs, as opposed to those with high conservation benefits and high conservation costs, would be prioritized for the CFW program, based on their positive ROIs. Third, we found that the benefits from the single ecosystem service of nutrient retention could exceed the conservation costs of the tax deductions and forgone alternatives (i.e., agriculture) if the program was targeted to contaminated watersheds. This research contributes to the integration of forest economics, forest conservation, and forest ecology to assess the effectiveness of forest conservation programs such as the CFW. It also informs citizens and governments on the benefits and costs of potential targeted increased enrollments of the CFW program in Indiana.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

Conservation investment for providing ecosystem services should be strategic because budgets are limited, and strategies might need to be spatially differentiated to account for ecosystem spatial heterogeneity (Murdoch et al., 2007; Naidoo and Ricketts, 2006). This is especially true for forest conservation where the ecological benefits and economic costs depend greatly on spatial distribution of land characteristics, land use, and land management activities. Conservation return on investment (ROI) analyses can help limited conservation budgets achieve greater conservation benefits (Naidoo and Ricketts, 2006). There have been increasing calls for assessing the effectiveness of conservation investments

(Ferraro and Pattanayak, 2006). The uptake of spatially explicit conservation ROI studies by governmental and non-governmental agencies is rare. This is perhaps due to the lack of user-friendly, streamlined, and systematic methodologies that incorporate spatially explicit ecological and economic costs and benefits to assess the return on investment of conservation programs.

Although it is common for economists to use the ROI approach for prioritizing an array of potential investment alternatives, conservation ROI was absent from systematic conservation planning until the late 1990s (Polasky et al., 2001). Prior empirical analyses drew heavily upon ecological analysis to set conservation priorities, or were instead applied economic analyses on valuing ecosystem services as they were impacted by land use change (Murdoch et al., 2007). Mapping and valuing ecosystem services by predicting changes in land use and land management are informative, but do not provide information on the effectiveness of conservation activities (Conte et al., 2012). Assessment of the effectiveness of conservation planning requires an additional step, which includes costs

as a decision-making factor to prioritizing conservation strategies (Ando et al., 1998). Incorporating conservation costs is especially crucial when direct and indirect costs are spatially heterogeneous, and there might be significant cost variation across candidate conservation strategies (Polasky et al., 2001; Balmford et al., 2003; Ferraro, 2003). Studies that incorporated conservation costs into conservation planning considered acquisition cost, management cost, or opportunity cost (Balmford et al., 2003; Chomitz et al., 2005; Naidoo and Adamowicz, 2005). Other studies incorporated conservation costs using aggregate measures, neglecting the spatial heterogeneity of these costs (Newburn et al., 2005; Naidoo and Ricketts, 2006). A few studies considered how the inclusion of spatially explicit conservation costs could affect the outcomes of conservation planning (Ferraro, 2003; Steward and Possingham, 2005). Ando et al. (1998) found that a single conservation benefit could amount to 25–50% of the total costs of conservation planning if spatial heterogeneity of biodiversity is considered. Ferraro (2003) found that 16% of total benefits are obtained by considering only biophysical characteristics on riparian buffer acquisition. Murdoch et al. (2007), Naidoo and Iwamura (2007), and Provencher et al. (2013) showed that ROI analysis can dramatically change site prioritization and yield better, and less costly, conservation outcomes.

Managed forests are capable of producing far greater flows of ecosystem services than unmanaged forests and this is especially the case for the provision of nutrient retention services (Iversen et al., 2010). Forest management can impact both the magnitude of nutrient output and the ability of lands to retain excess nutrients to downstream waterbodies. By managing timber stands, nutrient retention capacity for future cycling and use can be increased, and forestry best management practices (BMPs), such as closing forest roads and unblocking stream channels, can help prevent or mitigate the negative impact of increasing sediment, nutrients, and other pollutants during forestry (silvicultural) operations (McCoy, 2005; IDEM, 2005). Conserving private forests through conservation programs is considered a relatively cost-effective approach to purify water resources, thus reducing water treatment costs. For example, in a study of 27 water suppliers, Ernst et al. (2004) found that operating water treatment costs decreased by approximately 20% for every 10% increase in forest cover in a source area (Ernst et al., 2004).

There are two ways to achieve reduced nutrient loadings in a focal body of water: 1) Reduce nutrient export from the contaminant source; and 2) Increase vegetative filtration in the landscape. Reduction of nutrient pollutant loading through agricultural BMPs has received more attention among researchers than the increase of filtration in agricultural watersheds (Maringanti et al., 2011; Grossmann, 2012). From an economic standpoint, researchers have attempted to evaluate the reduction in nutrient loss from agricultural lands by using cost-effectiveness analyses (Fezzi et al., 2008; Mewes, 2012; Gachango et al., 2015) and mathematical programming methods (Gassman et al., 2006; Maringanti et al., 2011; Grossmann, 2012). Few studies have addressed the issue of mitigating nutrient runoff by increasing the vegetative filtration capabilities. Many studies quantified the nutrient retention services and their changes associated with wetland and riparian buffer (Thomas et al., 2007; Zhang and Mitsch, 2007; Smaill et al., 2011; Hoffmann and Kronvang, 2011; Weigelhofer et al.,2012; Jiang et al., 2014; McMillion et al., 2014).

Previous work made progress in developing market and non-market approaches to value the benefits of reducing the sources of water pollution at a local, state, or national level, and estimating the willingness to pay (WTP) to improve water quality in polluted aquatic systems (Carson and Mitchell, 1993; Lancelot et al., 2011; Nelson et al., 2015; Viscusi et al., 2008). The limitations of nonmarket valuation include the sensitivity of the results to numerous sources of bias in survey design and implementation, as well as being expensive and time-consuming (Kumar, 2010). Market-based methods include avoided cost methods, replacement cost methods, and restoration cost methods. The replacement cost approach (RPC) is based on estimating the cost that would be incurred if ecosystem service benefits need to be recreated through artificial means (Garrod and Willis, 1999). The RPC approach assumes that the costs people incur to replace the services of ecosystems can be substituted by what people paid to replace them through artificial means. For example, the nutrient retention services of a forest or wetland might be replaced by a water treatment plant. This method is most appropriately applied in cases where artificial means have been, or will be, made. The main limitation of the RPC approach is that costs are usually not an accurate measure of benefits (Barbier, 2007). It is difficult to estimate the cost of removing a specific nutrient pollutant due to the complexity of the treatment process.

This study assesses the impact of private forest management, rather than land-use changes, on the ecosystem service of nutrient retention in the White River Basin (WRB) of Indiana in the United States. We identify conservation priorities for forest conservation through ROI analysis at the subwatershed level (the finest watershed defined by the USGS) by developing hypothetical, spatially targeted forest conservation scenarios. We model spatially explicit conservation benefits and incorporate spatially explicit conservation costs including private forestland acquisition costs (forgone tax deduction) and opportunity costs related to alternative land uses.

2. Methods

We developed a spatially explicit conservation priority framework that incorporates ecological and economic models to compare alternative scenarios of increasing nutrient retention through the spatially targeted expansion of the Indiana Classified Forest and Wildlands (CFW) Program in the White River Basin of Indiana in the United States (Fig. 1). Specifically, our study includes the six following components: (i) spatially simulating and valuing nutrient retention service for the current CFW forests with InVEST nutrient retention model, (ii) assessing the prediction power of the InVEST model, (iii) estimating changes in the quantity and value of the nutrient retention service with hypothetical increases in the CFW enrollments, (iv) spatially estimating the conservation costs including acquisition and opportunity costs using ArcGIS, (v) applying conservation ROI analysis and comparing candidate scenarios, (vi) identifying potential conservation priorities for the CFW enrollments based on the ROI results.

2.1. InVEST nutrient retention model and materials

The InVEST Water Purification Nutrient Retention model estimates the contribution of vegetation and soil to purifying water resources through intercepting nonpoint sources of nutrient pollutants based on a simplification of a well-known hydrological and biophysical relationship. The model operates on an annual average basis with data formats in GIS raster grids, GIS shapefiles (Table 1) and tabular data (Table 2).

The model predicts nutrient export and retention service in two phases. The first phase calculates annual average water yield in each grid cell using the InVEST Hydropower Water Yield model based on climate data, geomorphological information, and land use and land cover (LULC) characteristics defined with ArcGIS. The InVEST water yield model employs the formulation of evapotranspiration based on the Budyko curve proposed by Fu (1981) and Zhang et al. (2004). The second phase determines the quantity