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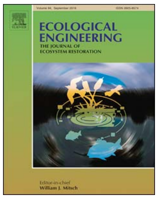

Short communication

Evaluating the net value of ecosystem services to support ecological engineering: Framework and a case study of the Beijing Plains afforestation project

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ABSTRACT

Ecological services were initially used to quantify the benefits used in valuation of environmental protection, as they helped stakeholders to understand the benefits that ecosystems bring to people. As a result, they increased support for ecological engineering, including ecosystem restoration. However, by failing to account for costs, and particularly for indirect costs such as the tradeoffs among ecosystem services under different land uses, the analyses were incomplete and often provided poor support for policy development and land management to promote environmental conservation. In this paper, we provide a framework for assessing the net value of the benefits provided by ecosystem services (i.e., the benefit that remains after subtracting key costs), taking the Beijing Plains afforestation project as an example. Furthermore, we analyzed the importance of scale effects and marginal changes in ecosystem services assessment, and highlighted the uncertainty of evaluation results caused by basing some of the analysis on market prices, which can change unpredictably. To better support conservation activities and maximize the ecological benefits obtained from an environmental strategy, it's necessary to obtain accurate estimates of the net value of ecosystem services by accounting for an increasing range of direct and indirect costs, calculated at the same scale as the project implementation and accounting for marginal changes, thereby providing better support for policy development and implementation.

1. Introduction

Ecosystems are dynamic and complex functional units formed by the interactions among plants, animals, microbial communities, and the inorganic environment (MA, 2003). Their complexity results from a seemingly infinite variety of feedbacks and adaptations that contribute to resiliency (Mitsch, 2012). Human society, as a "part of" nature and not "apart from" nature, must learn to recognize and sustainably use the resources provided by nature's functions, rather than using them unsustainably and damaging them, so as to provide a resilient and sustainable society (Mitsch, 2012).

Due to unreasonable and unsustainable human activities and the impacts of climate change, Earth's ecosystems have been seriously stressed (Rockström et al., 2009). Serious land degradation and other environmental problems have limited human development and begun to threaten humanity's survival. Therefore, the restoration and reconstruction of degraded ecosystems through sound ecological engineering provides a way to repair the damage or relieve the stress on these ecosystems, thereby improving the likelihood of sustainable development. Mitsch (2012) noted that the goal of ecological engineering is to find ways to let humans live in balance with their environment by combining changes in human activities (including land use) with restoration or reconstruction efforts designed to restore ecosystems to a stable state that is capable of sustainably providing the services required by both humans and nature.

When managers focus on ecosystem services as the goal of ecological engineering, this approach can help them to explain the benefits of ecological engineering to stakeholders in monetary terms; this can increase support for ecological engineering by expressing its value in terms familiar to those who will be affected by the changes (Jones, 2013). This approach helps governments and other land managers to communicate the values of intangible benefits such as biodiversity and ecosystem functioning, while simultaneously accounting for differences in the political, cultural, and economic perspectives of the stakeholders

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Fig. 1. From 2012 to 2015, Beijing City invested a total of 30 × 10^9 RMB to afforest 67 × 10^3 ha of the city's plains. About 70% of the trees were *Populus* and *Pinus Linn* species, which were planted with the goals of air purification and soil conservation (Chen, 2012).

(Gómez-Baggethun et al., 2010).

Costanza et al. (2014) defined ecosystem services as the "contribution of natural capital to human well-being". Alexander et al. (2016) summarized the discussion of natural capital by noting that this form of capital supports the ecosystem processes that allow ecosystems to function and provide services and benefits to both humans and nature. MA (2003) proposed a simple classification for these services: support services (e.g., food, freshwater), regulatory services (e.g., climate regulation, flood control), and cultural services (e.g., aesthetics, education). All of these categories directly support human life, particularly for the support services that are required to sustain the other services (e.g., soil formation, nutrient cycling). However, Wallace (2007) pointed out an important difference between ecosystem *services* and ecosystem *processes*: the former are defined in terms of specific human values, whereas the latter (and the natural capital that supports them) are not. In addition, it is not always clear how to define the data that should be used to calculate the values of a given ecosystem service, leading to the possibility of double-counting values when services overlap, and it is also possible to forget to include some services if the goals of a study are too narrowly defined.

Unfortunately, evaluating only the values of the services provided by an ecological engineering project does not guarantee the best decision. A more effective approach would be to evaluate both the benefits and the costs incurred to provide them (NRC, 2005; Zhang et al., 2016, 2017). Although there is a general consensus that it's necessary to evaluate the cost-effectiveness of an ecological engineering project (Wegner and Pascual, 2011), there is currently no standard framework for cost assessment. The boundaries between costs are still vague, leading researchers to potentially ignore some costs or double-count others. Therefore, it is necessary to carefully define both the values of ecosystem services and the costs incurred to provide them when the goal is to improve decision-making and promote sustainable development. By accounting for both the benefits and these costs, it becomes possible to calculate the *net* values of ecosystem services. In this article, we have taken the Beijing Plain afforestation project as an example to illustrate a framework for determining the net value of ecological services. Using this framework and data from the project area, we provide a more holistic assessment of the project by accounting for a wider range of costs than in previous research. In addition, we discuss the effects of both the project's scale and marginal changes, as well as the uncertainties in the results. Although the framework is based on China's approach to ecological engineering, the core concept is of great significance to environmental protection and restoration projects designed to promote sustainable development in other parts of the world.

2. A framework for decision support based on the net value of ecosystem services

To achieve the goal of achieving sustainable development, estimates of the value of ecosystem services (*VES*) in a given situation must not ignore the associated costs (*C*). On this basis, we can define the *net* value of ecosystem services (*NES*), which represents the net income after accounting for any costs (i.e., $NES = VES - C$). *C* is the cost that people must pay to receive ecosystem services, including the direct costs of investing in ecological restoration (C_d), the opportunity costs that result from using resources such as land and water in a given way compared with current or alternative uses (C_o), and the risk cost (C_r), which represents the cost of preventing various threats (such as fire and drought) to ecological and socioeconomic security:

$$C = C_d + C_o + C_r$$

Although the direct cost of investments in ecological conservation and restoration can usually be obtained from planning and budget documents, indirect costs are much more difficult to identify and estimate.

For a case study that demonstrates the use of this framework, we used a project to improve the quality of Beijing's environment and landscape. In this project, the city implemented a huge ecological engineering program, the Beijing Plains Afforestation Program (Chen, 2012; Fig. 1). This program, which focused on the flat land surrounding Beijing City, began in 2012 and ended in 2014. It was designed to improve the quality of Beijing's environment and landscape through the beneficial effects of tree planting (e.g., purification of air by trapping suspended particles, cooling of the climate through evapotranspiration, protection of the soil). In particular, the project targeted areas of degraded farmland, which both reduced the ecological services provided by food production and increased the risk of adverse consequences such as soil erosion.

In contrast to these opportunities for improving Beijing's ecological environment, there are several threats to the region's provision of ecosystem services. These include plantation failure (e.g., tree death due to drought), decreased food security due to the replacement of farmland with forest, damage to trees caused by insect and disease outbreaks, and impacts on the livelihoods of residents of the study area (e.g., the loss of farming jobs where degraded farmland was converted