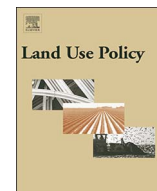




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Critical thresholds in ecological restoration to achieve optimal ecosystem services: An analysis based on forest ecosystem restoration projects in China

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ABSTRACT

Ecological restoration projects should ensure that multiple ecosystem functions meet the needs of different stakeholders. Ecological and economic thresholds are both indispensable to ecological restoration or land-use planning, but their joint application is often overlooked. Consequently, short-term benefits do not necessarily lead to long-term benefits. In this study, we emphasize the importance that ecological thresholds (based on sound ecological relationships between predictor variables and response variables) and economic thresholds (based on the needs of different stakeholders) be simultaneously evaluated during ecological restoration or land-use planning initiatives. They should replace composite indicators that do not reflect what transpires within ecosystems after a certain point in time. Although the assessment of a project's ecological and economic thresholds may be costly at the present time, this approach can effectuate the value of optimal ecological services and maintain it for a long period of time, while also improving resource use efficiency and sustainable development.

1. Introduction

Coupled human and natural systems (CHANS) have certain critical thresholds resulting from human disturbances to ecological systems, which have an important affect on ecological restoration and sustainability (Muradian, 2001; Collins et al., 2011; Liu et al., 2015). Ecological restoration refers to restoring degraded ecosystems back to their natural states or making them more adaptable to new environmental conditions, mainly through natural recovery and anthropogenic intervention (Jones, 2013; Crossman et al., 2017). Applying ecosystem services as the primary objective of ecological restoration projects would ease the evaluation and perception of these projects for the different stakeholders involved (Jones, 2013). Recently, scientific groups have recognized that identifying the costs of different ecosystem services from the perspective of cost-benefit analysis and establishing whether a threshold effect exists are both critical to making the best decisions (Turner et al., 2010; Zhang et al., 2017).

First proposed by physicists, “threshold” refers to the intersection between two different transformable states and the transitions from one state to another within a system as soon as this intersection is traversed (Huggett, 2005; Groffman et al., 2006). Since it was first proposed, the threshold concept has been widely applied to a diverse number of fields, such as ecology (e.g., optimal canopy densities) (Kerkhoff et al.,

2004) and economics (e.g., the environmental Kuznets curve) (Dinda, 2004). In fact, certain interactions occur between ecological and economic thresholds, which have an important influence on environment management decision making practices; however, only a few scholars have simultaneously analyzed the importance of such thresholds to date (Muradian, 2001; Collins et al., 2011).

For example, “panarchy”, a representative term that describes interactions between human societies and ecosystems, which views CHANS as a cross-scale nested set of adaptive cycles that reflect the dynamic nature of human and natural structures in space and time, is developing as a powerful conceptual framework for addressing scale issues (Groffman et al., 2006; Farley and Voinov, 2016). Furthermore, “Press-Pulse Dynamics” (PPD), introduced by Collins et al. (2011), is an iterative framework that combines biophysics and social sciences through the identification of the affects of human behavior on “press” and “pulse” events and ecosystem processes; events and processes that subsequently impact ecosystem services that, accordingly, modify human behavior that in turn triggers feedbacks, effectuating the initial events and processes. Additionally, Uehara (2013) defined an ecological economic threshold as the level of a resource stock below which natural stocks extirpate due to the interactions between ecological and economic systems. He also found that ecological economic thresholds may occur prior to ecological thresholds.

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However, due to the complexity of socio-ecological systems, key data obtained by means of a coupled threshold model may not in fact explain the physical meaning of such data. Additionally, neither does it explain the consequences of ecological and economic systems after obtaining such data, nor how people should react. To find a way out of this predicament, we analyze recent research related to forest ecosystem restoration in China and attempt to reveal the shortcomings in current research while exploring a path from which to effectively incorporate both ecological and economic thresholds into ecological restoration or land-use planning. We believe this study can further promote decision-making optimization as well as provide reference for natural resource management in other countries around the world.

2. The practical applicability of ecological thresholds for forest ecosystem restoration

The idea of ecological thresholds emerged in the 1970s from the viewpoint that ecosystems often exhibit multiple “stable” states, and shifts to different states are thought to be driven by external perturbations (e.g., climate fluctuations, overexploitation, and invasive species) or by the internal dynamics of ecosystems themselves (Groffman et al., 2006; Andersen et al., 2009). Groffman et al. (2006) compared ecosystems to “valleys of stability”, that is, “where the depth of the valley represented the systems’ “resistance” to disturbance and the steepness of the valley sides represented the systems’ “resilience” or the speed at which it would return to its stable state”. At a certain point, such disturbances can push a system beyond a threshold and into another valley or state (Fig. 1a). Some studies have shown that there are different response thresholds in both ecological restoration and degradation processes (Fig. 1b and c); however, this is not always the case. It often depends upon the temporal and spatial scale adopted (Muradian, 2001), and the dynamical characteristics of drivers and the status of ecosystems (Andersen et al., 2009).

China’s forest ecosystems have suffered serious damage resulting from natural disasters and economic development. Accordingly, the primary task of ecological reconstruction is the restoration of degraded forest ecosystems (Cao, 2011; Cao et al., 2011a). However, even though natural restoration would appear to be the best option under such circumstances, this approach would take a long time to meet peoples’ needs (Cao et al., 2011b). Therefore, based on natural laws, manual

intervention would be the preferred way by which to accelerate the restoration of degraded forest ecosystems (Cao et al., 2011b). Since the 1980s, China’s forest restoration initiative has resulted in significant short-term gains, but its failure in employing response thresholds has also triggered long-term consequences in the form of ecological degradation (Cao, 2011; Cao et al., 2011a). This is also true for southern China where even though a sufficient amount of water is available for afforestation initiatives, reasonable forest structure planning has not been adequate (Zheng et al., 2016).

For these reasons, scientists and environmental managers highly value thresholds for forest ecosystem restoration initiatives. For example, in their study on the restoration of degraded forest ecosystems in Changting County, Fujian Province, China, Gao et al. (2011) found that sustained degeneration of vegetation communities, erosion of surface soil, and declining soil fertility will occur when vegetation cover decreases below a specific degradation threshold (20%; Fig. 1b). Such data represent a critical threshold from which a system cannot be restored in the absence of comprehensive artificial restoration measures. In addition, Cao et al. (2017) investigated whether response thresholds exist for both natural and artificial restoration (Fig. 1c). They used tree cover as a predictor variable and other ecological indicators as response variables, such as plant species, shrub and grass cover, soil nutrients, and soil erosion moduli. They found that during the process of artificial restoration (i.e., afforestation), ecological parameters started to stabilize when tree canopy cover reached 48.5% in afforested plots approximately 10 yr following installation. However, their results showed that at present there is no obvious threshold for natural recovery processes.

Although these findings provide an important guide for local forest restoration initiatives, current recognized thresholds are still somewhat limited and highly uncertain against simple regression analysis of the observed data. As Qian and Cuffney (2012) pointed out, different models may produce different threshold estimates and only estimates that use the “correct” model are meaningful. Moreover, Qian (2014) added that in the context of selecting an appropriate threshold model, three sources of information should be used: patterns in model residuals, model predictions versus observations, and the posterior distribution of change points. Typically, F statistics are used to compute the ecological thresholds of time series (Andersen et al., 2009), and piecewise regression or step functions are used to obtain thresholds

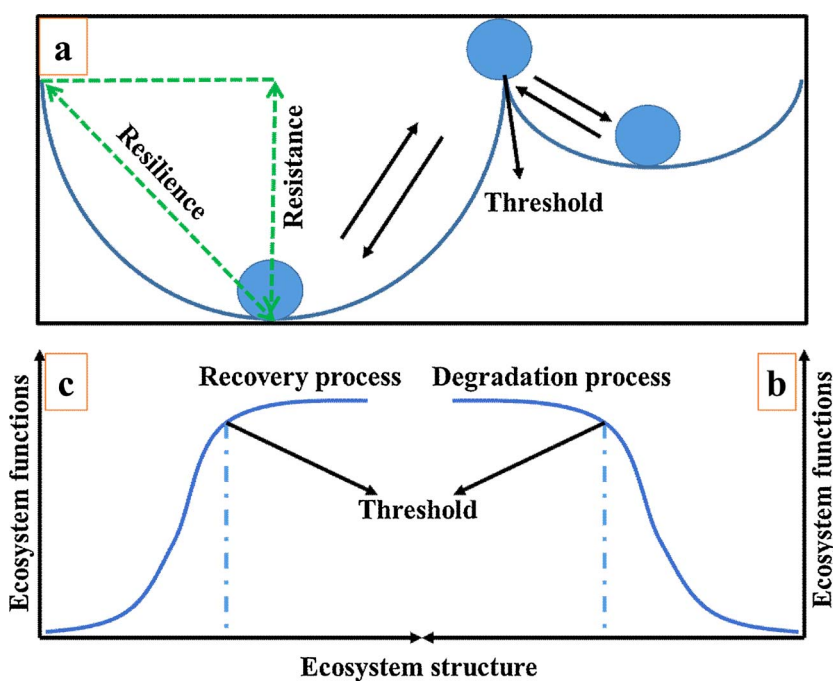


Fig. 1. Schematic diagram of ecological thresholds. (a) shows that there is a tipping point between different “stable” states (left and right); the depth of the valley represents the systems’ “resistance” to disturbances, and the steepness of the valley sides represents the systems’ “resilience” (revised from Groffman et al. (2006)). (b) shows the degradation threshold of an ecosystem, beyond which an ecosystem cannot be restored to its undamaged state. (c) shows a rational threshold of human intervention for ecological restoration, beyond which ecosystem functions will not increase significantly and will likely decline.

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