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# Gauging policy-driven large-scale vegetation restoration programmes under a changing environment: Their effectiveness and socio-economic relationships

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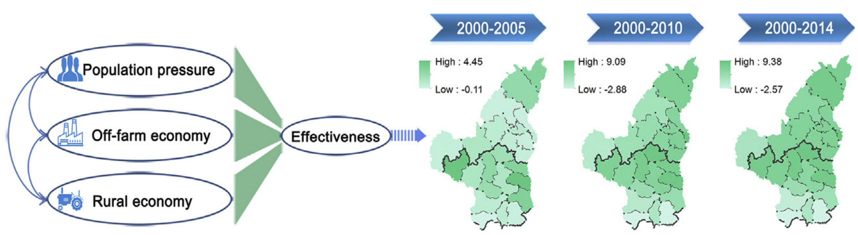
## HIGHLIGHTS

- A composite index to assess large-scale restoration effectiveness is formulated.
- Temporal scale is the crucial factor in representing restoration effectiveness.
- The effects of socio-economic factors on restoration effectiveness vary with time.
- Tertiary industry absorbing the rural labor force could alleviate population pressure.
- Improving the rural economy fundamentally could enhance restoration effectiveness.

## GRAPHICAL ABSTRACT




Impacts of socioeconomic factors on the restoration effectiveness    The effectiveness of vegetation restoration at county scale

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## ABSTRACT

Large-scale ecological restoration has been widely accepted globally as an effective strategy for combating environmental crises and to facilitate sustainability. Assessing the effectiveness of ecological restoration is vital for researchers, practitioners, and policy-makers. However, few practical tools are available to perform such tasks, particularly for large-scale restoration programmes in complex socio-ecological systems. By taking a "before and after" design, this paper formulates a composite index ($E_j$) based on comparing the trends of vegetation cover and vegetation productivity to assess ecological restoration effectiveness. The index reveals the dynamic and spatially heterogenic process of vegetation restoration across different time periods, which can be informative for ecological restoration management at regional scales. Effectiveness together with its relationship to socio-economic factors is explored via structural equation modeling for three time periods. The results indicate that the temporal scale is a crucial factor in representing restoration effectiveness, and that the effects of socio-economic factors can also vary with time providing insight for improving restoration effectiveness. A dual-track strategy, which promotes the development of tertiary industry in absorbing the rural labor force together with improvements in agricultural practices, is proposed as a promising strategy for enhancing restoration effectiveness. In this process, timely and long-term ecological restoration monitoring is advocated, so that the success and sustainability of such programmes is ensured, together with more informative decision making where socio-ecological interactions at differing temporal scales are key concerns.



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## 1. Introduction

Since the turn of the millennium, numerous restoration initiatives have been established across the globe to restrain environmental degradation and ecological destruction caused by human activities (Benayas et al., 2009). As an interventionist activity, evidence strongly indicates that ecological restoration has achieved its major goal of enhancing biodiversity and restoring ecosystem services (Clewell and Aronson, 2013). A meta-analysis of 89 restoration assessments across a wide range of ecosystem types, revealed that biodiversity and ecosystem services were on average enhanced by 44% and 25%, respectively (Benayas et al., 2009). Significant restoration achievements in some specific ecosystem types and degraded regions have also been reported (Calmon et al., 2011; Meli et al., 2014). As a result, ecological restoration activities are now widely recognized as significant contributors to global sustainability. Given the large spatial extent of restoration and conservation coverage, >11% of the global land surface (Andam et al., 2008), coupled with government funding, analytical tools are needed to accurately assess restoration effectiveness so that researchers and policy-makers can promote successful management interventions. Unfortunately, even well-designed research programmes are often poor at evaluating the effectiveness of large-scale ecological restorations (Martin et al., 2014). This is in part due to poorly specified metrics, limited information on spatial and temporal variability, and insufficient knowledge of human impacts. The lack of agreed scientific methods for assessing restoration effectiveness limits the incorporation of ecological restoration in land-use planning and decision making. In turn, this presents a challenge to governments and managers when restoration projects up-scale from individual sites to landscape and regional levels (Cao et al., 2009; Lamb et al., 2005).

Focusing on the temporal dimension of ecological restoration can provide detailed understanding of the effects of restoration activities (Levrel et al., 2012), and research has investigated temporal responses of different types of ecosystems to restoration initiatives. For instance, Jones and Schmitz (2009) compared ecosystem recovery and noted forest ecosystems took the longest to recover, with an average time of 40 to 50 years, whereas aquatic and terrestrial grassland ecosystems had much shorter recovery times of 20 to 25 years. Vegetation recovery in coastal marine and estuarine ecosystems has been found to take <5 years due to the short-lived and high-turnover nature of its biological components (Borja et al., 2010). In these cases, the focus was on the recovery of the ecosystem's structural characteristics without considering the degree to which functional ecosystem performance was regained. While a general consensus is that temporal scales of restoration strategies should not be ignored (Jones and Schmitz, 2009; McAlpine et al., 2016), few studies have established a restoration chronosequence that characterizes the dynamics and functionality of restored regions over time (Berkowitz, 2013).

In these evaluations, the process of ecological restoration is affected both by natural factors and by human activities, which provides multifaceted interactions between ecological effects and socio-economic drivers (Timilsina et al., 2014). In fact, recent research has indicated that socio-economic factors exhibit a growing influence on changes to ecological processes (Lü et al., 2015; Petursdottir et al., 2013; Zhang et al., 2013). The impacts caused by socio-economic factors were found to be dominant over climate variations, in driving large scale ecological changes nationally in China and related to the implementation of a series of large scale ecological conservation and restoration programmes (Lü et al., 2015; Zhang et al., 2013). However, detailed mechanisms concerning the role of socio-economic factors on ecological restoration effectiveness are still unclear at the regional scale. The purpose of this study is to tackle these deficiencies and to examine the effectiveness of large-scale ecological restoration over different temporal scales, as well as the possible time dependent relationships between restoration effectiveness and socio-economic factors.

In China, large-scale ecological restoration and conservation programmes, such as the 'Three Norths Shelter Forest System Project' (since 1978), the 'Natural Forest Conservation Program' (since 2000) and the 'Grain to Green Program' (GTGP, since 2000) have been established to support and promote ecosystem resilience, ecological security, and socio-economic sustainability (Lü et al., 2012), and ecological restoration policies have been established and refined. The GTGP is a large-scale programme converting steep cultivated land to forest and grassland. It was established in 1999 and was fully implemented in 2000 with 97% of China's counties involved (Liu et al., 2008). Central government offered farmers grain and financial subsidy every year based on the area of cropland on slopes that they converted (Liu et al., 2008; Miyasaka et al., 2017). The northern part of Shaanxi province in the central Loess Plateau was selected as a pilot and demonstration area for the GTGP. It provides a good case study to demonstrate a restoration effectiveness assessment toolkit in a regional scale. Here the vegetation cover has markedly increased since the late 1990s (Fan et al., 2015; Zhai et al., 2015), but also socio-economic factors such as population migration and industrial changes in this region has have an impact on restoration effectiveness.

Re-vegetation is the most intuitive and effective approach for restoration projects. It promotes ecological functions, such as increasing biodiversity, carbon sequestration and improved soil quality (Jin et al., 2014). Changes in vegetation provide simple and cost-effective indicators of effectiveness of restoration and conservation programmes (Lü et al., 2015). Using high temporal and high spatial resolution remote sensing data, it is possible to quantify the basic characteristics of vegetation/land cover change as well as changes in functional characteristics, such as biomass productivity. Fractional vegetation cover (FVC) can be derived from remote sensing data and used to provide an index for characterizing vegetation changes (Wu et al., 2014). Similarly, net primary production (NPP) provides a measure of standing biomass (Donmez et al., 2011) and is a critical indicator of ecosystem function (Watanabe and Ortega, 2014). Therefore, these two remote sensing data products were used to assess the effectiveness of regional ecological restoration in this research. Specifically, this research: (1) formulates a composite indicator approach for assessing the effectiveness of ecological restoration at a regional scale based on mentioned FVC and annual accumulated NPP; (2) quantifies the effectiveness of ecological restoration and the impacts from different socio-economic factors by using a structural equation modeling (SEM) approach; (3) highlights the significance of temporal scale effects and the practical implications of this research for ecological restoration policy and management across large spatial scales.

## 2. Materials and methods

### 2.1. Study area

Northern Shaanxi is situated in the middle of Loess Plateau (35° 21′–39° 34′ N, 107° 28′–111° 15′) and covers an area of $8.03 \times 10^4$ km$^2$ (Fig. 1). This region is dominated by a semi-arid and continental climate with a mean annual temperature ranging from 7 to 12 °C, and an annual precipitation ranging from 350 mm to 600 mm. The study area includes the Yulin and the Yan'an prefectures consisting of 25 counties, which acted has as a pilot and demonstration region for the GTGP since 1999 (i.e. over 15 years for the purposes of this study).

### 2.2. Data sources

The FVC and NPP data products were both derived from MODIS imagery with a 250 m spatial resolution from 2000 to 2014 during a 16-day time interval. The dimidiate pixel model for FVC estimation was calculated from the Normalized Difference Vegetation Index (NDVI) to assess vegetation response (Leon et al., 2012). The NPP data was computed based on the CASA (Carnegie-Ames-Stanford) ecosystem model (van