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Original article

Peri-urbanization may vary with vegetation restoration: A large scale regional analysis

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ABSTRACT

Over that past decade, ecological restoration practices have expanded globally. However, the effectiveness of ecological restoration depends on the complex interactions of various natural and socioeconomic factors, about which there is limited scientific understanding and thus provides an important research frontier. This paper analyzed the relationship between regional scale vegetation restoration and the process of urbanization using the Loess Plateau of China as a case study. This region has experienced both rapid urbanization and a high number of vegetation restoration activities. Urbanization and vegetation restoration can be considered as extremes on the spectrum of environment preservation activities. Three separate spatial correlation analyses between urbanization and vegetation restoration were identified, resulting in: 1) insignificant correlations in saturated urban areas; 2) significant negative correlations in *peri*-urban areas; and 3) significant positive correlations in undeveloped areas. The relationship between urbanization and vegetation restoration is thus stage-dependent. Impacts of urbanization on vegetation degradation has improved but has not been fully addressed by large scale vegetation restoration. Regardless of whether the county or grid scale is used, *peri*-urbanization was found to be the critical factor affecting the effectiveness of vegetation restoration over both time and space. Therefore, *peri*-urbanized areas are viewed as priorities for improving the coupling of urban development and vegetation restoration.

1. Introduction

The effects of urbanization on vegetation degradation have drawn increasing attention (Imhoff et al., 2004; Costanza et al., 2015; Pickens et al., 2017). Studies of the effects of urbanization on plant function in ecosystems at the landscape scale have mainly documented the loss of vegetation caused by the modification of farmland into urban land, for example in the United States (Milesi et al., 2003), in Europe (Gingrich et al., 2015), and in China (Tian and Qiao, 2014; Yu et al., 2009). At urban and regional scales, spatio-temporal correlations between urbanization and vegetation change indicators such as Fractional Vegetation Cover (FVC), Net Primary Productivity (NPP), Normalized Difference Vegetation Index (NDVI), and Leaf Area Index (LAI) have been explored (Lu et al., 2015; Morawitz et al., 2006; Liu et al., 2015). Research has found urban development to be negatively correlated with NPP, NDVI, and LAI (Xu et al., 2007; Buyantuyev and Wu 2009; Peng et al., 2015). With the expansion of ecological restoration practices globally (Boyer et al., 2016; Borchard et al., 2017; Wen et al., 2017), the effectiveness of such restoration interventions has become a key research topic. Plant biomass (Venson et al., 2017), carbon dynamics (Zhang et al., 2007) and vegetation cover change (Wiesmair et al., 2017) have all been used as proxies for assessing vegetation restoration implementation (Jiapaer et al., 2011; Bao et al., 2017).

Vegetation restoration and extensive urban land development can be considered as extremes on the spectrum of environment preservation and greatly affect carbon sequestration and other ecosystem functions (Zhang et al., 2007). However, the effectiveness of ecological restoration depends on the complex interactions of various natural and socioeconomic factors, about which scientific understanding is limited and thus provides an active research frontier. In particular, this article addresses the following research questions. What are the correlations in space and time between outcomes when vegetation restoration practices and urbanization occur simultaneously? Can negative correlations between urbanization and vegetation properties be identified when vegetation restoration trends are incorporated into the analysis? How effective is vegetation restoration at each stage of the process of

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Fig 1. Location of the Loess Plateau.

urbanization?

As a case study, we use the Loess Plateau of China, where both rapid urbanization (i.e. the Western Development Program) and the practice of returning farmland to forest and grassland (i.e. the Grain for Green Program) have been implemented since 1999 (Feng et al., 2016; Kou et al., 2016). The Loess Plateau is located in an arid and semi-arid area, and this type of habitat accounts for about 40% of the total global land surface (Warren et al., 1996). Therefore, this study contributes to a deeper scientific understanding of the coupling of urbanization and vegetation restoration at regional scales, in water limited environments, facilitating sustainable policies towards urban development and regional ecological integrity.

2. Material and methods

2.1. Research area

The Loess Plateau, the largest area of sedimentary loess in the world, lies in the upper reaches of the Yellow River in China, between 33°43′–41°16′N and 100°54′–114°33′E (Fig. 1). It encompasses an area of about 621,400 km^2, and a total of 332 counties and county-level cities. From south to north, the Loess Plateau crosses both the warm temperate and temperate zones. From east to west, it spans semi-humid, semi-arid and arid areas and features typical continental climate characteristics. The ~400 mm of annual precipitation is seasonal with widely variable local rates. The evaporation rate is large and the frost-free period is short. This area has one of the most serious soil erosion problems in China and globally. Soil erosion has exacerbated the deterioration of the environment in this area and unsustainable land uses have intensified the rate of soil erosion. Therefore, since 1999, China has implemented a policy of returning farmland to forest and grassland, in an effort designed to achieve vegetation restoration. This mitigates the widespread and severe soil erosion along with other parallel improvements in ecological function, such as carbon sequestration and habitat provision (Fu et al., 2011; Feng et al., 2016; Wang et al., 2016).