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Effect of ecological engineering projects on ecosystem services in a karst region: A case study of northwest Guangxi, China

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ABSTRACT

Ecological efficiencies of rocky desertification control measures at the regional scale remain unclear. It is urgent and challenging to determine the influences of ecological engineering on the variations of ecosystem services, and to evaluate the ecological benefit of rocky desertification control measures. In this study, variations of three kinds of ecosystem services (water regulation, soil conservation, and carbon sequestration) were analysed in a typical karst region of Northwest Guangxi China during the period from 2000 to 2010. The relative importance of the main factors that influence these three ecosystem services were analysed using radial basis function network, Kaiser–Meyer–Olkin (KMO), and principal component analysis. The results showed that over half of the study area has experienced an increase in water regulation (50.39%) and soil conservation (58.53%), and approximately 28.24% of the study region has undergone increased carbon sequestration. Environmental factors had a substantial impact on the ecosystem services, and the order of relative importance was as follows: geology > soil > vegetation > temperature > precipitation. Anthropogenic activities have played an important role in the changes to the ecosystem services. In addition to the significant conversion of other land types to woodland (approximately 46.80% of the total transfer area), the vegetation species, shape, and fraction, which are greatly influenced by human activities, contributed 79.05% to the variance. This resulted in a high KMO value of 0.912 (>0.9, represents very suitable), and the Bartlett test was significant (Sig. 0.00). These results showed that although natural environmental factors remained basic influences on the pattern of ecosystem services, anthropogenic activities of ecological engineering projects also had important and positive influences on the ecosystem services. This study also indicated that satellite images and new methods should be applied to deal with the relative lack of existing datasets.

1. Introduction

Ecosystem services refer to the benefits provided by natural ecosystems (Cord et al., 2015). They are influenced by a wide range of factors, including geology, elevation, and socio-economic activities (Cao et al., 2015). It is estimated that 60% of the ecosystem services worldwide are degraded as a consequence of anthropogenic activities, such as increase in population and economic development (Joppa et al., 2016). Several measures have been taken to protect the ecological environment. The Grain-to-Green Program (GTGP) is the largest ecological restoration program in China, with an ambitious goal to rehabilitate the degraded and disturbed ecosystems, which was started in China in 1999 (Li et al., 2016). A systematic project of eco-environmental migration (EEM) for improving the production and living conditions of farmers is also under way (Feng et al., 2013). These two programs seek to alleviate human pressure on the natural ecosystems. However, because of the complexity of the ecosystem, information regarding different ecosystem services, such as water conservation, soil conservation, carbon sequestration, and biodiversity should be obtained using different methods (Zhang, et al., 2011b). In addition, it remains a challenge to log and evaluate the impact of human activities on the

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ecosystem and its services (Ouyang et al., 2016).

The karst regions account for approximately 15% of the terrestrial land area and are inhabited by approximately 17% of the world population (Jiang et al., 2014). These regions are characterized by shallow soil (generally ≤ 10 cm in depth) (Ouyang et al., 2011), and a lack of surface runoff (infiltration coefficient of 0.3–0.6 or even 0.8) (Chen et al., 2011). One of the most extreme manifestations in such areas is rocky desertification, which is characterized by a high percentage of barren rocks and a low vegetation cover, and is associated with very low land productivity (Cheng et al., 2017; Xu et al., 2013). In the karst region of Southwest China, such features have led to the dual problems of poverty and environmental degradation. To solve these problems, a considerable number of desertification control measures are emerging as the key modes for achieving sustainable development, because of inadequate natural resources available to the forced migrants and fragile environment. A great deal of ecological engineering, including GTGP and EEM, has been carried out since 1999 in the fragile ecological environment regions of Northwest Guangxi China, where desertification and erosion are severe (Zhang et al., 2016). The purpose of the GTGP is to improve the vegetation coverage, whereas EEM aims to assist farmers in relocating from the karst regions to non-karst regions, where ecosystem conditions are better. During the EEM campaign, 49,133 families (232,705 individuals) were relocated in the Northwest of Guangxi China (Tong et al., 2017). In the process of GTGP, 605.33 km^2 of farmland and 673.33 km^2 of barren hills were converted to woodland in Baise county from 2001 to 2004 (Zhang et al., 2016). During the period from 2000 to 2010, the implementation of GTGP in the counties of Northwest Guangxi was significant, reaching 4.5 $km^2\,yr^{-1}$ in some of the counties (Zhang et al., 2016).

Therefore, many scholars are interested in the karst ecosystem, and in recent years, an increasing amount of attention has been paid to the geological background, the characteristics of climate change, variations in soil nutrients, geological drought, water adaptation strategies of plants, and the adaptability of plant species (Xu et al., 2015). However, only a few studies have investigated the changes in ecosystem services and the efficiency of rocky desertification control projects (Tong et al., 2017). Most of the existing research on the relevant ecological effects of rocky desertification control measures or ecosystem services focuses on the changes in one ecosystem service (vegetation carbon, water conservation, or soil conservation), and a variety of ecosystem services are not considered simultaneously. Further, studies addressing the efficiency of ecosystem services have concentrated primarily on the micro scale by employing *in situ* methods (Zhang, et al., 2011a). Based on field investigations, sampling, and pot experiments, the characteristics of soil organic carbon, water regulation, or biomass, after the implementation of desertification control measures, were analysed and predictions were made on a community or ecosystem scale (Nie et al., 2012; Zhang et al., 2012). In contrast, there have been relatively few studies at the regional scale, which have tended to consider spatial variations only over 3-year periods, or have focused on qualitative analysis of the natural factors influencing the ecosystem services in the karst regions (Zhang, et al., 2011b). Consequently, the ecological efficiencies of rocky desertification control measures, at the regional scale, as well as the impact of human activities on the ecological services, remain unclear. This situation has arisen because of the relative lack of datasets for historical reasons, and the difficulty in estimating the impact of ecological engineering on the ecosystem services.

Therefore, there is an urgent need to understand the spatiotemporal variation in ecosystem services, and the effects of GTGP and EEM on these services, in the karst regions, to evaluate the efficacy of rocky desertification control measures. The Radial basis function network (RBFN) is an artificial neural network model that is widely used because it can approximate any continuous function with any precision (Schwenker et al., 2001). The Kaiser–Meyer–Olkin (KMO) is used to compare the correlation coefficients between variables in test statistics (Mathur, 2014), and principal component analysis (PCA) is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables (Mao et al., 2017). To a certain extent, they can compensate for the lack of relative lack of data and provide the relative importance of the factors. Therefore, based on the evaluation of multiple ecosystem services, using the RBFN model, combined with the analysis of the results obtained using KMO and PCA, the effects of rocky desertification control measures on ecosystem services were evaluated in this study. The main objectives of this study were as follows: (a) To quantify the spatiotemporal variation in ecosystem services (water regulation, soil conservation, and carbon sequestration, and (b) to explore the impact of natural factors and anthropogenic activities on ecosystem services in a karst region of Northwest Guangxi, China.

2. Study area

The study region of Northwest Guangxi is located in the southwest karst region of China (104°29′–109°09′E, 23°33′–25°37′N), and includes 16 counties, covering a total area of 50,700 km^2. The elevation ranges from 100 to 2000 m, with a decrease in elevation from northwest to southeast. Limestone is widespread (>50%) and karst caves have developed. The area is notable for its karst landforms (Fig. 1). This area has comparatively small agricultural land (<20%), which is typically low yielding and is mainly distributed in the canyon areas that are inhabited (Zhang et al., 2016). Therefore, there is a conflict between agricultural development and ecosystem conservation in these areas.

The climate is of the subtropical monsoon zone, with annual average temperature of approximately 16–22 °C. The precipitation is abundant, with an average annual rainfall of approximately 1500–1800 mm, but the distribution of rainfall is uneven in any particular year. The precipitation is concentrated over 4–9 months (usually resulting in flooding). The period from October to the subsequent March represents the dry season (which is often under the threat of drought). The hydrological conditions are complex because the geology has resulted in mature underground rivers (Nie et al., 2017). The soil is shallow (<1 m), and is mainly composed of lime developed from dolomite (>50%), which is easy to mineralize or is present in loose form (Nie et al., 2017). The vegetation is abundant with evergreen broad-leaved forest (>50%) (Tong et al., 2017).

3. Materials and methods

3.1. Data acquisition

In the present study, a continuous moderate-resolution imaging spectro-radiometer (MODIS) dataset was used (Table 1). This dataset was obtained from http://ladsweb.nascom.nasa.gov/. The Landsat images were downloaded from http://www.geodata.cn. A continuous dataset (2000–2010) of daily meteorological data from 97 stations within and near the study area was acquired from http://cdc.cma.gov.cn/. The other data selected for this study, such as soil type, vegetation type, geology type, hydrology type, elevation data layer, and forest inventory data were obtained from the sources detailed in Table 1. These datasets were resampled at 100-m resolution using a thin-plate smoothing spline method. The