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Quantifying the spatial correlations between landscape pattern and ecosystem service value: A case study in Ebinur Lake Basin, Xinjiang, China

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ABSTRACT

Human activities and environmental degradation have resulted in landscape structure changes and can eventually affect the ecosystem service value (ESV) of its region. Nevertheless, research on the spatial correlations between ESVs and landscape pattern changes is lacking. Thus, 13 landscape metrics and nine ESV types in Ebinur Lake Basin were chosen and used to analyse their spatial correlations using multiple linear regression models in this study. The results revealed that eight out of the 13 landscape metrics showed direct spatial correlations with ESV type, and there were landscape metrics that were positively and negatively correlated with the different ESV types. The interspersion and juxtaposition index (IJI), patch richness (PR), and patch richness density (PRD) had no effects on the provision of ESVs. The results also showed that the land-use/land-cover classification types play a linking role, as changes in land-use/land-cover affect the provision of ESVs and the fragmentation of landscape patterns. At the same time, the total ESV of Ebinur Lake Basin was 21.21×10^9 CNY in 2014. Wood and grassland contributed the highest ESV in Ebinur Lake Basin, i.e., 16.29×10^9 CNY, followed by water bodies and farmland, i.e., 1.785×10^9 CNY and 1.239×10^9 CNY, respectively. The regression models that were obtained quantitatively assessed how the changes in landscape patterns have affected the provision of ESVs. These models greatly contribute to the application of the ecosystem service approach in research as well as in practice and provide a better understanding of landscape planning in Ebinur Lake Basin.

1. Introduction

Landscape pattern is the combination of natural and human-managed patches (Turner, 1987; Hulshoff, 1995). The analysis of landscape pattern is a major focus of landscape ecology (Zhang et al., 2011), and the changes in landscape pattern affect the movements of organisms and matter (MA, 2005); in turn, landscape patterns impact the provision of ecosystem services (Brauman et al., 2007; Mitchell et al., 2013; Qiu et al., 2016), which are essential to sustaining life on earth and maintaining ecosystem integrity (Costanza et al., 1997; Kozak et al., 2011; Graves et al., 2017). Human activities, i.e., mainly agricultural activities, settlements, construction lands and mining (Groot et al., 2012; Haines-Young et al., 2012; Bryan, 2013), and natural habitat fragmentation have changed the landscape patterns, and these changes have accounted for the impacts on ESV (Kindu et al., 2016; Tolessa et al., 2017).

Inappropriate land-use patterns can modify hydrological systems, genetic resources, nutrient cycles, energy flows, and species compositions (Zhao et al., 2004; Alberti, 2008), which can change landscape fragmentation and eventually threaten the supply of ecosystem services (Groot et al., 2012), leading to ecosystem degradation. Landscape fragmentation affects ecosystem provisioning and disrupts the buffering capacities of ecosystems for human and natural communities, including the capacities for flood protection, climate regulation, and the control of diseases and pests (Cai et al., 2016). Quantifying and analysing the correlation between landscape pattern and ESV would provide sufficient information for monitoring the indicators and implementing managing strategies for sustainable development, which would help determine the costs of restoration and assist in payments for ecosystem services (Costanza et al., 1997; Groot et al., 2012; Alarcon et al., 2016).

Various studies have analysed landscape patterns and their relations with ecosystem services (Frank et al., 2012; Mitchell et al., 2015); most

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of these studies have revealed the impacts of land-use/land-cover changes on the provision of ESV. At the same time, landscape patterns at different spatial scales have been characterized and mapped throughout the world using remote sensing (RS) and geographic information system (GIS) tools (Zimmermann et al. 2010; Liu et al. 2014), and the responses of ecosystems have been further analysed. However, not all ecosystem service types, such as regulating and supporting services, have been equally included in the research on the effects of landscape patterns on individual ESV type (Eigenbrod, 2016). Furthermore, it is not completely understood that how ESV responds to changes in landscape patterns (Mitchell et al., 2014), and the quantification of the spatial correlation between landscape patterns and ecosystem services is also poorly understood. Studying the relationship between ESV and landscape patterns is critical to assess how changes in landscape patterns could affect ESV. Accurate models should be obtained and utilized to guide landscape planning for stakeholders.

Changes in landscape patterns play an important role in sustaining and fulfilling human life in China, especially in the arid region of Xinjiang. Increasing human and domestic animal populations in Xinjiang have resulted in overgrazing, farming, and urbanization as well as industrialization, which have caused changes in landscape patterns and serious environmental degradation, such as soil salinization and desertification that increases floating dust and sandstorms, all of which eventually contribute to ESV losses (Mamat et al., 2014; Abulizi et al., 2017; Mamat et al., 2017). When water evaporates or shrinks, the lake sediments do not provide material to the ecosystem of the region (Zhang et al., 2017), which has a lowering effect on the provision of ESV in Ebinur Lake Basin. Then, a new means of material losses called the lake bed effect, as well as soil salinization, have emerged (Zhang et al., 2015a). The unique geography and ecology of Ebinur Lake Basin have easily disturbed the ecological processes in this region, and ecosystem degradation, i.e., salinization and desertification, would affect the development of the Bortala Mongol Autonomous Prefecture and the Silk Road Economic Belt in Xinjiang, as well as the sustainable development of Xinjiang's society and economy.

Therefore, this study attempts to test the main hypothesis that not all landscape metrics positively affect the provision of ESV in this region. At the same time, the motivation of this study is (i) to analyse the effects of the extents of landscape pattern changes on the provision of ESV, (ii) to include all ecosystem service types into the research on the effects of landscape patterns on individual ESV types, and (iii) to develop ideal multiple linear regression models to quantify the spatial correlation between landscape patterns and ecosystem services. The results of the study can be utilized for policymakers to create suitable regional landscape plans.

2. Study area

Ebinur Lake Basin (43°38′ to 45°52′N and 79°53′ to 85°02′E) is located in northwestern Xinjiang Uygur Autonomous Region, China, and is surrounded by Bortela Valley to the west, the Jinghe proluvial fan to the south, and the Gobi Desert to the east (Fig. 1). The total area of Ebinur Lake Basin is 50,621 km^2. The areas of the surrounding mountains and plains are 24,317 km^2 and 26,304 km^2, respectively (Leng et al., 2006). Temperate and arid climate zones predominate in Ebinur Lake Basin; the annual precipitation in this region ranges from 100 to 200 mm, and the annual potential evaporation ranges from 1500 to 2000 mm. Furthermore, the western wind current, the Mongolian high-pressure systems and the Siberian freezing air affect the weather in this region (Zhang et al., 2015a).

Maximum precipitation occurs in the summer, and the snow cover is shallow in the winter, ranging from 10 to 25 cm annually and persisting until late February or early March. The mean July temperature is +27 °C, and the mean temperature is −17 °C (Zhang et al., 2015b) in January.

3. Materials and methods

3.1. Data preparation

Remote sensing (RS) data are valuable sources of spatially and temporally explicit information (Corbane et al., 2008). In particular, multi-spectral satellite imagery provided by Landsat TM and ETM images are precious resources for analysing surface processes at a regional scale (Alatorre and Begueria, 2009; Liberti et al., 2009). To assess the correlation between ESV and landscape metrics in Ebinur Lake Basin, Xinjiang, a Landsat 8 OLI image from 2014 was downloaded from http://www.gscloud.cn/. The Landsat 8 OLI image data from 2014 utilized in this study were obtained during the dry season and were free of clouds. To eliminate factors such as dust, haze, smoke, and solar angle variations, atmospheric correction and radiometric normalization were performed before geometric correction. After using the ENVI image processing model to geometrically correct and rectify the image on the basis of the National 1:50,000 Basic Terrain Database, ArcGIS10.1 software was used for spatial analysis (Yun et al., 2011). The average squared error was less than two pixels after geometric correction and rectification.

3.2. Land-use/land-cover classification

The image of Ebinur Lake Basin was classified into six types using supervised classification and visual interpretation: farmland, wood and grassland, water bodies, lake bed, salinized land, and other. The classification methods were based on the land-use/land-cover classification in China's national land resource classification system with the current land-use/land-cover conditions of Ebinur Lake Basin (Liu et al., 2005; Yu et al. 2017). During the classification process of the Ebinur Lake Basin image, a total of 600 training sites were developed from high-resolution images that were released from Google Earth (Google, 2015) for better visual interpretation (Yu and Gong, 2012; Sabr et al., 2016), and the training sites were homogeneous groups of pixels that represented the land-use/land-cover classification types that were identified in the image (Matinfar et al., 2007). The maximum likelihood classification algorithm in the supervised classification method (Karakus and Karabork, 2016) was used to assign the homogenous groups of pixels to the identified land-use/land-cover classification types. The descriptions used in the land-use/land-cover classification types are shown in Table 1.

It is common that certain features such as mountains that are covered with snow are misinterpreted as water, or desert areas are often misinterpreted as salinized land (Jain et al., 2016). Therefore, the final misinterpreted patches amongst all classes need to be recorded in the correct class, which is based on unsupervised classification. The classification results were post-processed by reclassifying the misinterpreted classes and utilizing unsupervised algorithms to improve the classification accuracy. In addition, we conducted an accuracy evaluation survey of the classified images using ground truth observations, which were collected from 87 sampling points using GPS coordinates across the entire study area. The classification accuracy of the image exceeded 80.3% by using both supervised classification and unsupervised classification (Jain et al., 2016) (Fig. 2).

The land-use/land-cover classification data in Ebinur Lake Basin were automatically processed to generate a grid with a spatial resolution of 20 km, which divided the study area into 145 grid cells. These grid cells were used as the basic units in the correlation between ESV types and the landscape metrics at the landscape level and helped to demonstrate the distribution of ESV in each unit. The land-use/land-cover change of the study area is characterized by high homogeneity as the areas are dominated by similar ecosystems and landscape structures within the spatial resolution of 20–30 km. When the spatial resolution of the grid was smaller than 20 km, more grid cells would have similar landscape structures, leading to data redundancy. At the same time,