Ecological Indicators 89 (2018) 110–117

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Changing patterns in farming–pastoral ecotones in China between 1990 and 2010

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ARTICLE INFO

Keywords:
Farming-pastoral ecotone (FPE)
Landscape pattern
Remote sensing
Land cover
Ecological protection policies

ABSTRACT

The farming-pastoral ecotone (FPE), defined as the mosaic of transition zone between traditional farming and pastoral regions, is sensitive to climate change and human disturbance. Extensive farming activities within and along FPEs have led to alarming environment degradation in China in the past several decades. Many ecological protection policies have been deployed to improve the structure and function of current FPEs. However, the changes in national FPE patterns as a result of farming activities and ecological protection policies have rarely been quantified using a robust dataset. Therefore, in this study we quantified two-decades of FPE change patterns in China using spatial autocorrelation and spatial clustering methods, along with land use data at 10 year intervals from 1990 to 2010. The results show that the derived FPEs in the north, middle, and south sections along the Hu's Line underwent remarkable spatio-temporal changes. The north and middle FPEs shifted from the southeast to northwest during the period of 1990–2000, mainly because of extensive farming activities. However, this trend slowed in the north FPE, and reversed in the middle FPE in the 2000s, mainly attributed to the deployment of ecological protection policies. As there are limited farming activities in mountainous terrains, the south FPE did not show notable changes compared with the north and middle FPEs. The PFE changes caused predominantly by extensive agricultural activities and ecological protection policies were then further quantified through transition matrix analyses between FPEs, farming areas (FA), and pastoral areas (PA). Our study suggests that new FPE maps derived from satellite remote sensing could provide a straightforward methodology to quantitatively evaluate the effect of agricultural activities and environmental policies on vulnerable FPE regions.

1. Introduction

Ecotones, defined as transition zones between landscape units (Metzger and Muller, 1996), are very sensitive to changes in the surrounding environment (He and Cui, 2015; Kamel, 2003; Reich et al., 2015). The farming-pastoral ecotone (FPE) is the mosaic transition zone between traditional farming and pastoral regions. The FPE can also be depicted as the region where farmlands invade into grassland boundaries (Liu et al., 2011). Significant attention has been placed on Chinese FPEs, where serious degradation has occurred owing to a rapid increase in farming and social-economic activities (Allen and Breshears, 1998; Lu and Jia, 2013; Xu et al., 2014). The desertification area in northern FPEs accounted for 36.5% of the total desertification in China in the late 1980s, and this ratio increased to 90% in 2000, at a rate of approximately 2000 km^2 per year (Zhang and Li, 2000). In order to mitigate the environment degradation and achieve regional sustainable development, the Chinese government implemented a series of environmental protection and restoration policies, such as the Grain for Green (GFG) program, and directives for mitigating overgrazing in pasturing regions in the late 1990s (Delang and Yuan, 2015; Liu and Wu, 2010). These policies have changed land cover patterns; the implementation of the GFG program effectively decreased cultivated lands in or along FPEs after 2000 (Liu et al., 2014). However, in order to improve evaluations of policy effectiveness, the quantification of land use/land cover changes derived from satellite remote sensing images before and after policy implementations is a promising method. To date, however, such quantitative evaluations on environmental protection and restoration policies are rarely reported.

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https://doi.org/10.1016/j.ecolind.2018.01.067
Received 20 July 2017; Received in revised form 29 January 2018; Accepted 31 January 2018
1470-160X/

Several methods have been proposed to define FPEs based on the views of economic geography, agricultural climate, agricultural regionalization, and ecology (Fortin et al., 2000; Hufkens et al., 2009; Wu and Guo, 1994). Researchers that use climate indices to define FPE generally agree on the 400-mm isohyet to be the centerline, but have different opinions on the values of other indices to delineate the boundaries including the humidity index, inter-annual precipitation variability and threshold values of mean annual precipitation (Liu et al., 2011; Zhao et al., 2002). Wu and Guo (1994) proposed that the ratio of areas in cropland, grassland and forestland should be 1:0.5:1.5 to define the FPE in Northern China. However, the FPEs derived from these methods only delineate vague spatial boundaries with specific characteristics of climate, agriculture, economy, or ecology. FPE mapping using remote sensing-based land use/land cover with fine resolutions would provide a straightforward method to accurately quantify the geographic pattern of FPEs and their spatiotemporal changes.

In this study, we aim to map FPEs using land use data, investigate spatial and temporal changes in FPEs, and quantitatively evaluate the effects of protection policies on FPE changes in China during the past two decades.

2. Methodology

2.1. Data and preprocessing

Land use data with a spatial resolution of 1 × 1 km on a national scale were used to map FPEs in China in 1990, 2000, and 2010. The land use data product was accessed at the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC, CAS; http://www.resdc.cn). The national land use dataset was developed at a spatial scale of 1:100,000 by visual interpretation and digitalization using Landsat TM/ ETM images and China-Brazil Earth Resources Satellite (CEBRS-1) images. Numerous field investigations have proved that the land use classification of this dataset had an accuracy of more than 90% (Liu et al., 2002; Liu et al., 2003, 2014), which can meet the requirement of mapping FPE accuracy on the 1: 100,000-scale.

The area-percentage data model (APDM) has been extensively used to analyze the spatial-temporal features of land use change (Deng et al., 2006, 2010; Wang et al., 2010), and was utilized in this study to create a set of continuous variables for land use data. This data preprocessing was implemented using the Fishnet and Aggregate modules in ArcGIS (Liu et al., 2011; Tucker, 2000).

2.2. Mapping FPEs and drawing the study area

Spatial autocorrelation and spatial clustering methods could be combined to map FPEs in China (Xiao and Zhang, 2008) (Fig. 1). Spatial autocorrelation measures the degree to which a set of spatial features tend to be clustered (Legendre, 1993). To detect the heterogeneity of spatial features, in this study, the Local Indicators of Spatial Association (LISA) approach was used to evaluate the degree of spatial autocorrelation (local Moran's I) and the statistical significance of each point (Anselin, 2013).

The model equations are as follows:

$$I_i = \frac{(n-1)(X_i-\overline{X})}{\sum_{j=1,j\neq i}^{n}(x_j-\overline{x})^2}\sum_{j=1,j\neq i}^{n}\omega_{ij}(X_j-\overline{X}) \tag{1}$$

$$z(I_i) = \frac{I_i-E(I_i)}{\sqrt{\mathrm{var}(I_i)}} \tag{2}$$

where I_i is the value of Local Moran's I in position i, n is the number of research objects, X_i is the observed value, X_j is the neighbor of X_i, $\overline{X}$ is the mean of X_i, ω_{ij} is the spatial weight between research objects, and $z(I_i)$ is the LISA z-test, which was tested at the 95 percent confidence level.In this study, FPEs were mapped through generating the area-percentage for cropland and grassland, producing maps of spatial clustering for cropland and grassland, and overlaying the clustering maps. Detailed procedures were shown in Fig. 1. Firstly, the APDM was used to generate continuous variables for cropland and grassland in 10 × 10 km grids. Secondly, the I_i values of cropland and grassland were calculated for all grids and then the significance test for I_i and the spatial clustering analysis were conducted using the GeoDa V1.6.7 tool (Anselin et al., 2006). Then the spatial clustering maps of cropland and grassland were outputted from the GeoDa tool based on the combination of I and p values. The clustering results of both cropland and grassland were divided into 5 types, respectively, including High-High (HH), Low-Low (LL), High-Low (HL), Low-High (LH), and Not Significant (NN). HH and LL, representing statistically significant clusters with high I values and low I values, indicate croplands (or grasslands) are highly clustered and dispersed in space, respectively. Both HL and LH, representing statistically significant spatial outlier data, indicate a high area-percentage value surrounded primarily by low area-percentage values (HL) and a low area-percentage value surrounded by high area-percentage values (LH), respectively. NN indicates no statistically significant in spatial cluster ($p > 0.05$). According to the criteria of spatial clustering classification (Table 1), thirdly, the paired cropland and grassland clustering maps were used to generate 4 landscape types, including Farming area (FA), Pastoral area (PA), Farming-Pastoral ecotone (FPE), and the Other area (OA).An artificial study area was defined to provide a reference space over which changes in FPEs could be quantified. Two steps were implemented to determine the study area (Fig. 2). Firstly, three FPE maps from 1990, 2000, and 2010 were overlain to obtain a merged map. Then, the merged map was extended away from the boundary by a distance of 100 km using the ArcGIS buffer tool. This distance was determined by considering the maximum moving distance of FPE boundaries during the period of 1990–2010 was less than 100 km.

2.3. Transition matrix for analyses of land use changes

The transition matrix was used to quantify the conversions among investigated landscape types between two given dates. In this study, four landscape types were investigated, including FA, PA, FPE and OA.

3. Results

3.1. New Chinese FPE maps derived from land use data

Three new FPE maps from 1990, 2000, and 2010 across China were generated (Fig. 2). The FPEs cover 757 counties in 19 provinces, and accounts for about 37.7% and 59.4% of all the counties and provinces in China, respectively. Considering the vast differences in spatial patterns and geographical conditions, the Chinese FPEs were divided into three sections (north, middle, and south) for detailed investigations.Fig. 2 shows that the derived FPEs are located along the Hu's Line from the northeast to southwest of China. The Hu's Line, from the city of Heihe to Tengchong County, is a symbolic geographical line that divides China into two roughly equal parts, and was put forward by Huanyong Hu (Hu, 1990). This straight line was essential to understanding the spatial patterns of Chinese climate, terrain, population, and economy. Rather than rough spatial patterns of FPEs referring to economic development, agricultural climate, agricultural regionalization, and ecology, the satellite-based FPEs can be used to quantify accurate spatial patterns and areas. The cumulative average area of Chinese FPEs is 1.56×10^6 km^2, accounting for about 1/5 of China's land area.