Spatial heterogeneous response of land use and landscape functions to ecological restoration: the case of the Chinese loess hilly region

Jianglei Wang · Yihe Lü · Yuan Zeng ·
Zhijiang Zhao · Liwei Zhang · Bojie Fu

Received: 23 May 2013 / Accepted: 22 February 2014 / Published online: 15 March 2014
© Springer-Verlag Berlin Heidelberg 2014

Abstract Ecological restorations over time may have profound effects on ecological and socio-economic systems. However, land-use changes and landscape functions that accompany ecological restorations can have spatial differentiations due to varied biophysical and socio-economic contexts. Therefore, these spatial differentiations caused by ecological restoration must be understood for better planning and management of restoration activities. The Baota District, with 576 villages in the center of the Chinese Loess Plateau, was selected as the study area because of its dramatic transition from cropland to grassland and shrubland from 1990 to 2010. Using the ArcGIS software and a *k*-means clustering analysis, an approach to identify types of land-use change patterns (TLCPs) at the village level was developed, and four TLCPs were delineated. The analysis indicated a general pattern of cropland decline by 21.6 %, but revealed significant spatial variations between villages in different TLCPs. Vegetation cover and soil retention, which are key proxies for landscape functions, increased by 22.70 and 108 %, respectively, from 2000 to 2010 with significant spatial heterogeneity. The Universal Soil Loss Equation was

employed for the assessment of soil retention. The analysis of landscape metrics revealed a major trend of fragmentation and regularity on the county and village scale; however, spatial variations remained. Physical attributes were used to characterize different TLCPs, and notable differences were found. The spatial heterogeneous change in land use and landscape functions on the village scale may be useful for land use and ecological restoration management policy makers.

Keywords Land-use changes · Landscape metrics · *k*-means clustering · Spatial heterogeneity · Ecological restoration · Landscape function · USLE

Introduction

Land degradation, which is a decline in land quality that is caused by human activities, has become one of the most serious ecological problems worldwide (Harris 2003). Land degradation is not merely an environmental issue, but can also have profound socio-economic impacts (Feng et al. 2004). Therefore, the need to restore degraded land has never been more pressing. Ecological restoration is an important approach to mitigate this problem (Hobbs and Harris 2001). To repair damaged ecosystems and to develop sustainably, many ecological restoration projects have been implemented globally (Moore et al. 1999; Sutherland 2002; Leigh 2005; Vishnudas et al. 2012). Simultaneously, many studies have been performed that evaluate the effects of ecological restoration projects (Qi et al. 2013; Harris 2003; Singh et al. 2012; Ye et al. 2011; Zhang et al. 2012). From these studies, many have found that ecological restoration can induce significant land-use changes across spatial and temporal scales (Singh et al.

J. Wang · Y. Lü (✉) · L. Zhang · B. Fu
State Key Laboratory of Urban and Regional Ecology, Research
Center for Eco-Environmental Sciences, Chinese Academy of
Sciences, PO Box 2871, Beijing 100085, China
e-mail: lyh@rcees.ac.cn

Y. Zeng
Institute of Remote Sensing and Digital Earth, Chinese Academy
of Sciences, Beijing 100101, China

Z. Zhao
College of Landscape Architecture and Forestry, Qingdao
Agricultural University, 700 Great Wall Road, Chengyang
District, Qingdao 266109, Shandong, China

2012; Qi et al. 2013; Zhang et al. 2012; Huang et al. 2012). However, most of these studies only provide a general description of the land-use change process on the landscape scale (Qi et al. 2013; Huang et al. 2012). Few studies have attempted to further inspect the process at finer scales and to reveal the complex relations between ecological restoration and land-use change.

Land-use change is the collective outcome of a myriad of processes: socio-economic, institutional, biophysical and ecological, which make this process complex and heterogeneous (Álvarez Martínez et al. 2011; Bürgi and Turner 2002; Reid et al. 2000). Furthermore, land-use change, in turn, can have profound influences on social, economic and ecological systems (Munroe and Müller 2007; Liu et al. 2011; Sun et al. 2011). In regions that have suffered from severe land degradation, ecological restoration can be an important driving force and be influenced inevitably by the land-use change this degradation has induced. These complex relations are extremely important for scientists, landscape managers and policy makers to understand when designing cost-efficient ecological restoration strategies (Álvarez Martínez et al. 2011).

Landscape functions describe the performance of a landscape in the broadest sense. Landscape functions indicate the capacity of natural processes and components to provide goods and services that directly and/or indirectly satisfy human needs (Syrbe et al. 2007). Landscape functions would change along with land-use changes (Zucca et al. 2013), particularly during ecological restoration (Ren et al. 2013). Subsequently, the evaluation of changes to landscape functions, and its spatial heterogeneity, along with ecological restoration, is crucial to assess the performance of large-scale ecological restoration projects and can provide scientific support for decision making.

The loess hilly area in China lies in the middle reaches of the Yellow River. This region has suffered from serious soil erosion, which was primarily caused by irrational land use and low vegetation coverage (Chen et al. 2001; Zhang et al. 2004b). The Chinese government has increasingly monitored this serious problem, and several ecological restoration projects that are aimed at soil and water conservation have been implemented since the 1980s (Zhang et al. 2004b; Yin and Yin 2009). In 1999, a national-scale reforestation project, which is known as the Grain to Green Project (GTGP), was launched, and the loess hilly area was the pioneer and demonstration area of this large project (Wang et al. 2007; Lü et al. 2012; Liu et al. 2008). The main practice of this reforestation project was converting cropland on steep slopes ($\geq 25^\circ$) or cropland with low yield into forests, which induced significant land-use changes along with reducing soil erosion.

The Baota District of the Yan'an prefecture in the Northern Shaanxi province of the Chinese Loess Plateau

was chosen as a case study area to analyze the heterogeneity of land-use change that was induced by ecological restoration from 1990 to 2010. The specific objectives were (1) to classify the villages according to spatial heterogeneous land use and its change between 1990 and 2010, (2) to characterize the land-use change by physical factors and by landscape metrics, and (3) to evaluate the change in vegetation and soil retention that was induced by ecological restoration from 2000 to 2010.

Materials and methods

Study area

The case study area, the Baota District ($36^\circ 10' 36''$ – $37^\circ 02' 05''$ N, $109^\circ 14' 10''$ – $110^\circ 05' 43''$ E), is in the center of the Yan'an prefecture in the Northern Shaanxi province of the Loess Plateau, and covers an area of 3,536.8 km² (Fig. 1). In 2011, this district had a population of 462,389, 63 % of which were rural. This region has a typical semi-arid continental climate, with an average annual rainfall of approximately 500 mm with high variability (61 % of the rain falls between July and September) (Zhang et al. 2004b). This region lies in the core area of the loess hilly area in China and has suffered from the most serious soil erosion in the middle reaches of the Yellow River, which makes this district a key region of ecological restoration. The Baota District is composed of 576 villages according to the second national land survey of China. This area has experienced long-term soil and water conservation and was selected as one of the pioneer and demonstration areas for the large-scale ecological restoration project that was known as Grain to Green in China (Chen et al. 2007; Lü et al. 2011, 2012).

Land-use classification and pattern analysis

Land-use classification

In this study, five remote-sensing images were used to produce multi-temporal sets of land-use maps of the Baota District for 1990, 2000 and 2010, separately. Three Landsat 5 Thematic Mapper (TM) images were from July and August 1990 and June 2010. Two Landsat 7 Enhanced Thematic Mapper (ETM) images were from June 2000. An object-oriented classification, which was based on decision trees using eCognition software (DeFinis 2004), was performed to classify the land use into seven types: forest, shrubland, grassland, cropland, residential area, water body and barren land. Then, manual correction was applied to ensure the accuracy of the classification. The accuracies of the classified products were assessed by manual interpretation using the program Google Earth Pro®. In total, 5 %

Fig. 1 Map of the study area showing its location in China and its topographical situation

of the patches that were larger than 15 hectares were chosen randomly as samples. Using the spatial join function in the program ArcMap (version 9.3), the results of the manual interpretation and the original results of these selected samples were compared to produce confusion matrixes (Munroe and Müller 2007). The accuracies of maps in all 3 years were above 94 %. Finally, the Kappa indices were calculated, and the results were above 0.88 for all 3 years. These values met the accuracy requirement for land-use change analysis (Janssen and Wel 1994).

The land-use changes at the county level from 1990 to 2010 were analyzed by the area and by the area change in each land-use type between the two periods. Land-use transition and contribution matrixes were generated to reveal the detailed land-use transformations for the two time intervals from 1990 to 2010.

The administrative division map on the village level was obtained from the second national land survey of China. The land-use maps were overlaid with the administrative map using the union function in the ArcGIS 9.3 Analyst

tool to produce maps that contained information regarding both the land cover type and the administrative division, which were then used to generate ten quantitative indicators in each village for cluster analysis. See the detail of the ten indicators in the footnote of Table 5.

Landscape pattern analysis

To assess the changes in structural characteristics of landscapes under different scales, the program FRAG-STATS 4.1 (McGarigal et al. 2012) was used to calculate the following four landscape metrics: mean patch size (MPS), patch density (PD), Shannon's diversity index (SHDI) and interspersed and juxtaposition index (IJI). These metrics are frequently used to assess the structural characteristics of landscapes and to monitor changes in land use (Zhou et al. 2012; Benini et al. 2010; Uuemaa et al. 2013). The expressions were as follows (McGarigal et al. 2012):

$$\text{MPS} = \frac{A}{N} \left(\frac{1}{10,000} \right) \quad (1)$$

where A is the total landscape area (m^2), and N is the total number of patches in the landscape, excluding any background patches.

$$\text{PD} = \frac{N}{A} (10,000) (100) \quad (2)$$

where N is the total number of patches in the landscape, and A is the total landscape area (m^2).

$$\text{SHDI} = - \sum_{i=1}^m (P_i \times \ln P_i) \quad (3)$$

where P_i is the proportion of the landscape that is occupied by patch type (class) i .

$$\text{IJI} = \frac{- \sum_{i=1}^m \sum_{k=i+1}^m \left[\left(\frac{e_{ik}}{E} \right) \cdot \ln \left(\frac{e_{ik}}{E} \right) \right]}{\ln(0.5[m(m-1)])} (100) \quad (4)$$

where e_{ik} is the total length (m) of the edge in the landscape between patch types (classes) i and k ; E is the total length (m) of edge in the landscape, excluding background; and m is the number of patch types (classes) that are present in the landscape, including the landscape border, if present.

All the metrics were calculated using the entire study area and four TLCPs for the 3 years (1990, 2000 and 2010). A brief description of the metrics that were used in this study is listed in Table 1.

Topographical analysis

The elevation and slope were selected to characterize different types of land-use change patterns (TLCPs). These

Table 1 Brief description of landscape metrics

Metric name	Acronym	Units	Description
Mean patch size	MPS	ha	Average size of patches is expected to decrease with increasing fragmentation
Patch density	PD	Number per 100 ha	PD expresses number of patches on a per unit area basis; PD for a particular patch type could serve as a good fragmentation index
Shannon's diversity index	SHDI	None	Diversity measure; increases with number of patch types and as the proportional distribution of area among patch types become more equitable
Interspersion and juxtaposition index	IJI	%	Approaches 0 when distribution of adjacencies among patch types becomes increasingly uneven; IJI equals 100 when all patch types are equally adjacent to all other patch types

two factors were identified as important physical attributes in relation to land-use change in several studies (Yong et al. 2006; Chen et al. 2001; Pineda Jaimes et al. 2010; Hietel et al. 2004).

Elevation data were obtained from the U.S. Geological Survey's ASTER Global Digital Elevation Model (AST-GTM, 30 m, https://lpdaac.usgs.gov/products/aster_products_table/astgtm). The median elevations, which were expressed as meters, were determined within each TLCP. The slope was calculated from the DEM by the use of the slope function in the ArcGIS 9.3 Spatial Analyst tool. Within each TLCP, the slopes were classified into three classes: $<15^\circ$, 15° – 25° , and $>25^\circ$ (to describe the slope as a percentage, 15° and 25° are equal to 26.8 and 46.6 %, respectively).

Cluster analysis

To classify TLCPs for 576 villages, a k -means clustering analysis was performed using the software SPSS 20.0. The k -means cluster classifies objects into a user-defined number of clusters according to the number of user-selected quantitative traits (Edwards and Cavalli-Sforza 1965).

Because cluster analysis is sensitive to broad ranges in data values, the data were standardized to z scores. A z score, which is also called a standard score, is the (assigned) number of standard deviations that an observation or datum is *above* the mean. The standard score of a raw score x is

$$z = \frac{x - \mu}{\sigma} \quad (5)$$

where x stands for the raw score of ten variables, μ is the mean, and σ is the standard deviation. The villages were allocated into different clusters by minimizing the variability within clusters and maximizing the variability between clusters. To determine the optimized number of clusters, the analysis was performed for different numbers of clusters that ranged from 3 to 6. The preliminary analysis results showed that few clusters resulted in a large variability between villages in the same cluster, whereas many clusters produced a strongly unbalanced distribution of villages, with small clusters that were composed of few villages. Therefore, the rules for determining the optimized number of clusters should be the number of villages in every cluster must be above 25, and simultaneously, the square sum of deviations within clusters must be the smallest.

Vegetation cover change estimation

NDVI time series data from 2000 to 2010 were used to calculate the vegetation cover of the study area. The NDVI series data were obtained from an 8-day MODIS NDVI dataset of 250 m from 2000 to 2010. The data set was provided by Geospatial Data Cloud, Computer Network Information Center, Chinese Academy of Sciences (<http://www.gscloud.cn>). The formula was as follows (Fu et al. 2011):

$$\text{Vegetation} = \frac{\text{NVDI} - \text{NVDI}_{\text{soil}}}{\text{NVDI}_{\text{max}} - \text{NVDI}_{\text{soil}}} \quad (6)$$

where $\text{NVDI}_{\text{soil}}$ is the NDVI of bare soil and NVDI_{max} refers to the regional maximum NDVI.

Using the ENVI 4.8 software, 11 vegetation cover maps from 2000 to 2010 were acquired. Using the least squares method, a map of the vegetation cover change trend was calculated.

Soil conservation assessment

The Universal Soil Loss Equation (USLE) was employed for the soil erosion control assessment with localized parameters. Because of a lack of vegetation cover data before 2000, only the soil retention between 2000 and 2010 was analyzed. The soil retention was calculated as the potential soil erosion (erosion without vegetation cover) minus the actual soil erosion (Fu et al. 2011; Bangash et al. 2013).

According to Wischmeier and Smith (Wischmeier and Smith 1965), the formula is defined as the following:

$$A = R \times K \times L \times S \times C \times P \quad (7)$$

where A is the amount of soil loss ($t\text{ hm}^{-2}\text{ year}^{-1}$), R stands for the rainfall erosivity factor ($\text{MJ mm hm}^{-2}\text{ h}^{-1}\text{ year}^{-1}$), K is the soil erodibility factor ($t\text{ h MJ}^{-1}\text{ mm}^{-1}$), L is the slope length factor, S stands for the slope factor, C is the dimensionless vegetation cover factor, and dimensionless P refers to the soil conservation practice.

If both C and P are assigned the value of 1, then there are no surface soil coverage or land management practices. Then, the calculated soil erosion is the potential soil erosion (A_p), which is calculated as follows (Fu et al. 2011; Su et al. 2012):

$$A_p = R \times K \times L \times S \quad (8)$$

The amount of soil retention can be estimated by the difference between the potential soil erosion and the actual soil erosion. The new formula is as follows (Fu et al. 2011; Su et al. 2012):

$$A_r = A_p - A_v = R \times K \times L \times S \times (1 - C \times P) \quad (9)$$

where A_r is the soil retention, which is a consequence of the vegetation cover and soil conservation practice; A_p is the potential soil loss, and A_v is the soil loss under the current land use/cover condition.

Rainfall erosivity factor (R)

The rainfall erosivity factor (R) was calculated using the Wischmeier empirical formula (Wischmeier WH 1978):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \times \lg \frac{P_i^2}{P} - 0.8188\right)} \quad (10)$$

where P_i is the monthly rainfall (mm) and P is the annual rainfall (mm).

Soil erodibility factor (K)

The K factor describes the vulnerability of the soil to raindrop detachment and runoff wash and is determined by soil type. The clay content is a major factor of soil erosion resistance on the Loess Plateau. Based on a study of runoff plots of the Loess Plateau, Zhang et al. (2004a) established the following simple formula for the relation between the K factor and the soil clay content:

$$K = 0.031 - 0.0013\text{CL} \quad (11)$$

where CL is the clay content (%). The data were obtained from the China Soil Map Based Harmonized World Soil Database (Fischer et al. 2008).

Topographical factors (L , S)

Topographical factors included L (slope length) and S (slope gradient). The formulas for L and S are defined as the following (Su et al. 2012):

$$L = \left(\frac{\lambda}{22.13} \right)^m \begin{cases} m = 0.5 & \theta \geq 9 \\ m = 0.4 & 9 > \theta \geq 3 \\ m = 0.3 & 3 > \theta \geq 1 \\ m = 0.2 & 1 > \theta \end{cases} \quad (12)$$

$$S = \left(\frac{\sin \theta}{0.0896} \right)^{0.6} \quad (13)$$

where λ is the slope length (m), and m is a dimensionless constant that is dependent on the percent slope (θ).

Vegetation cover factor (C) and erosion control practice factors (P)

The C factor is closely related to the vegetation cover. The formula for the C factor in this study followed Fu et al. (2011) and is expressed as:

$$C = \begin{cases} 1, & f = 0 \\ 0.6508 - 0.3436 \times \lg f, & 0 < f \leq 78.3 \% \\ 0, & f > 78.3 \% \end{cases} \quad (14)$$

where f is the vegetation coverage and is calculated using the NDVI that is derived from MODIS images. The formula is identical to formula (6).

Regarding the P factor, the slope gradient is a key factor for determining the soil loss on the Loess Plateau of China. For this reason, the slope-based Wener method (Lufafa et al. 2003) was applied to calculate the P factor, as shown below:

$$P = 0.2 + 0.03 \times \alpha \quad (15)$$

where α is the percentile slope gradient.

Meteorological data analysis

Temperature and precipitation data for the study area from 1981 to 2010 were obtained from the China Meteorological Data Sharing Service System (<http://cdc.cma.gov.cn/home.do>). Using the raster calculator function in the program ArcMap (version 9.3), the average temperature and precipitation from 1981 to 2010 were calculated.

Results and discussion

Land-use change and transitions at the county level

The land-use patterns in this region have experienced dramatic changes during the last 20 years, particularly

from 2000 to 2010 (Fig. 2; Table 2). From 1990 to 2010, cropland decreased from 1203.23 to 943.84 km², whereas grassland increased from 1,013.37 to 1,201.46 km². In addition, shrubland experienced a growth from 907.16 to 948.60 km². In contrast, forest cover remained unchanged. This lack of change is primarily because large-scale afforestation began in 1999 and because the trees were too small to be perceived as forest at a 30-m ground resolution in 2010 (Zhou et al. 2012). In the study area, the main deciduous tree species of afforestation was black locust (*Robinia pseudoacacia* L.), and it would take more than 10 years for locust seedlings to become large trees under the semi-arid climate. Thus, in 2010, the newly reforested land still appeared as shrubland in canopy density and spectral features. These four land-use types (forest, shrubland, grassland and cropland) accounted for 98 % of the total area; thus, further analyses focused on these four types. Overall, cropland decreased sharply, by 21.6 %, whereas grassland and shrubland increased by 18.6 and 4.6 %, respectively, from 1990 to 2010.

Two transition matrixes (Tables 3, 4) were calculated to help understand the land-use conversion among land-use types between two neighboring periods. There were no noticeable transitions between 1990 and 2000. Significant changes occurred after 2000, and the decrease in cropland was the general change pattern. The majority of the vanishing cropland contributed to grassland and shrubland, whose increase accounted for 75 and 16 %, respectively. These two land conversions (i.e., cropland to grassland and cropland to shrubland) were the two main types of land transformation that were induced by the ecological restoration.

Fortunately, losing cropland did not greatly affect the incomes of rural residents. According to the statistical yearbook of the Baota District, from 2000 to 2010, the per capita annual net income of rural residents increased from 1,487 to 6,379 RMB Yuan (180–934 US Dollars). Before 2000, the income from agriculture could account for as much as 62 % of the total income for farming households. In 2010, this proportion decreased to 41 % (Zhang and Gao 2008). Simultaneously, the salary income increased rapidly to fill in the gaps from the declining agriculture income. The salary income increased from 11 % of the total income in 2000 to 30 % in 2010 (Xu et al. 2008).

Clusters of landscape pattern change at the village level

Despite the general pattern at the landscape scale, significant spatial heterogeneity of land-use change was detected at the village scale. Using a k -means cluster analysis, which was based on the spatial heterogeneous land-use change information, each of the 576 villages was grouped into one of four types of land-use change clusters (TLCP I to TLCP IV) (Table 5).

Fig. 2 Land-use composition and configuration in the Baota District since 1990 **Table 2** Land-use changes between 1990 and 2010

	1990	2000	2010
(a) Land-use changes in areas (km ²)			
Forest	387.74	387.76	387.76
Shrubland	907.16	907.29	948.60
Grass	1,013.37	1,030.34	1,201.46
Crop	1,203.23	1,181.58	943.84
Residential area	11.39	16.80	41.26
Water body	13.89	13.00	13.85
Barren land	0.04	0.04	0.04
(b) Land-use changes in percentage (%)			
Forest	11.0	11.0	11.0
Shrubland	25.6	25.7	26.8
Grass	28.7	29.1	34.0
Crop	34.0	33.4	26.7
Residential area	0.3	0.5	1.2
Water body	0.4	0.4	0.4
Barren land	0.0	0.0	0.0

There are significant differences in the land-use conditions and changes between the TLCPs (Table 5). These types divided the study area into different subregions (Fig. 3). The villages of the northernmost part are classified as TLCP I, which is the predominant type that covers 38.7 % of the study area. These villages are characterized by the highest proportion of cropland (48.6 %) in 1990, and the percentage for cropland conversion to grassland (10.3 %) is the highest (Table 5). TLCP IV is similar with TLCP I in all aspects

Table 3 Land-use transition matrix between 1990 and 2000

1990–2000 (km ²)						
2000	1990					
	FR	SL	GL	CL	RA	WB
FR	385.6			0.1		
SL		906.6		0.5		
GL			1,018.7	18.3		0.2
CL		1.3	1.0	1,175.5		0.9
RA				5.5	10.8	
WB				0.1		11.6

Land cover types abbreviations: *FR* forest, *SL* shrubland, *GL* grassland, *CL* cropland, *RA* residential area, *WB* water body

Table 4 Land-use transition matrix between 2000 and 2010

2000–2010 (km ²)						
2010	2000					
	FR	SL	GL	CL	RA	WB
FR	385.7					
SL		907.0	0.4	39.6		
GL			1,018.9	190.2		
CL			13.4	926.7		0.9
RA			3.8	20.4	16.3	0.1
WB			0.7	1.8		10.6

Land cover types abbreviations: *FR* forest, *SL* shrubland, *GL* grassland, *CL* cropland, *RA* residential area, *WB* water body

Table 5 Description and results of land-use data of the types of land-use change patterns (TLCP I–IV)

TLCP	Area (km ²)	Number of villages	FR90 (%)	SL90 (%)	GL90 (%)	CL90 (%)	FR10 (%)	SL10 (%)	GL10 (%)	CL10 (%)	CL2SL (%)	CL2GL (%)
I	1,369.7	323	0.03	5.96	44.81	48.63	0.03	6.79	53.35	38.22	0.71	10.33
II	913.7	175	2.63	31.06	23.66	40.75	2.65	31.79	28.57	31.61	0.60	5.55
III	1,119.9	52	25.35	41.84	12.24	20.28	25.35	41.91	14.95	17.48	0.09	2.54
IV	113.5	26	0.46	4.57	46.71	48.10	0.46	20.64	48.63	30.11	17.55	2.24

FR90, SL90, GL90 and CL90 are the percentage area of forest, shrubland, grassland and cropland, respectively, in a village in 1990. FR10, SL10, GL10 and CL10 are the percentage area of forest, shrubland, grassland and cropland, respectively, in a village in 2010. CL2SL is the percentage of area transformed from cropland to shrubland in a village from 1990 to 2010. CL2GL is the percentage of area transformed from cropland to grassland in a village from 1990 to 2010

Fig. 3 Spatial distribution of the types of land-use change patterns (TLCP I–IV)

except that most of the decreased cropland converted to shrubland. TLCP IV is also characterized by the highest proportion of cropland decline (37.4 %). However, TLCP III villages in the southern part present an exact contrast with TLCP I villages, which are characterized by a high proportion of forest and shrubland and by a low proportion of grassland and cropland. Moreover, TLCP III villages are the most stable with the lowest percentage of decline in cropland (13.8 %). The TLCP II cluster, with most villages in the central part of the study area, is moderate in every variable.

The TLCP I villages were always dominated by cropland and grassland, and the two land-use types accounted

for more than 90 % of the area. In contrast, the TLCP III villages had the most varied landscape characteristics with the four major land-use types evenly distributed. Overall, there was a pattern toward a more evenly balanced distribution of different land-use types in all four TLCPs, which was in accordance with that shown on the county level.

Changes in landscape pattern metrics on different scales

The results of landscape metrics showed that the long-term ecological restoration had created more fragmented and diversified landscapes, as evidenced by the decrease in the

Fig. 4 Changes in landscape metrics on landscape and village scales. **a** Changes in the mean patch size (MPS); **b** changes in the patch density (PD); **c** changes in Shannon's diversity index (SHDI); **d** changes in the interspersion and juxtaposition index (IJI)

MPS and by the increase in the PD and SHDI on the landscape scale (Fig. 4). The increase in the IJI showed a more interspersed and even distribution of land-use types, which was also revealed by the landscape composition analysis.

Although most villages have the same pattern as that exhibited at the landscape scale, there remains some spatial variations on the village scale. The TLCP I villages have the highest MPS and the lowest PD among the four TLCPs. In contrast, the TLCP II villages are the highest in the PD and the lowest in the MPS. These villages all experienced a slight increase in the IJI and SHDI. The IJI of the TLCP III villages decreased slightly, which indicates a disproportionate distribution of land-use type adjacencies that is opposite to the entire study area and to villages in the other three TLCPs. The TLCP III villages are the most active in all three metrics, which indicate a more remarkable change in structural characteristics.

When considering the results of “Clusters of landscape pattern change at the village level”, more interesting observations were found. The TLCP IV villages, with the highest proportion of cropland loss, experienced the most significant change in all four metrics, whereas the TLCP I villages, which also had a high proportion of cropland loss, remained stable in the four landscape metrics that were analyzed. The TLCP III villages remained stable in the

MPS, the PD and in SHDI, while experiencing a sharp decrease in the IJI. This result indicated that the changes primarily occurred in the landscape configuration. The TLCP II villages were the highest in the PD, SHDI and in the IJI, while the lowest in the MPS, which indicates a more fragmented and diversified, but poorly interspersed, landscape.

Changes in the vegetation cover fraction

The average vegetation cover fraction increased greatly from 2000 to 2010 (Fig. 5), from 60.34 to 74.13 %. The change trend of the vegetation cover fraction from 2000 to 2010 ranged between -4.73 and 4.74 %, and the average was 1.45 %. To inspect the spatial variability, the trend of vegetation cover changes was reclassified into three classes: decrease (where the trend was below 0), slight increase (where $0 < \text{trend} < 3$ %) and significant increase (where the trend was above 3 %). The results showed that the vegetation cover increased in 96 % of the study area, and 10.07 % of area experienced a significant increase. In contrast, in areas where cropland transferred to shrubland and grassland from 2000 to 2010, 99.64 % of area showed an increase pattern, 23.69 % of which experienced a significant increase. In addition, in areas where cropland transferred to shrubland, the percentage of significant

Fig. 5 Vegetation cover trend from 2000 to 2010

increase area was 42.29 %, which was far above the percentage in areas where cropland transferred to grassland, which was 19.81 %. The results showed that the GTGP caused a sharper increase in the vegetation cover, particularly in areas where cropland transferred to shrubland. Converting cropland to shrubland was a better practice than converting cropland to grassland concerning vegetation recovery in the study area.

There were also differences between the four TLCPs. TLCP IV had the highest proportion of significant increase in area (38.00 %). TLCP I and TLCP II had similar performances, with a proportion of significant increase area percentage of 19.50 and 20.28 %, respectively. In contrast, in TLCP III villages, 6.95 % of the areas had a negative trend, and only 0.45 % of the areas had a significant

increase pattern. This result could be partly explained by different land-use change processes, as stated in “[Clusters of landscape pattern change at the village level](#)”.

Changes in the soil retention

Since 2000, the average soil retention (Fig. 6) increased by 93.5 %, from $4,815 \text{ t km}^{-2} \text{ year}^{-1}$ to $9,318 \text{ t km}^{-2} \text{ year}^{-1}$. The soil retention increased in the entire area and sharply increased (above $10,000 \text{ t km}^{-2} \text{ year}^{-1}$) in 5.73 % of the area. Variations were significant between the four TLCPs. According to the average increase in the soil retention, the four TLCPs could be ranked as TLCP III > TLCP II > TLCP I > TLCP IV. In TLCP III, 9.02 % of the area

Fig. 6 Soil retention in 2000 and in 2010 **Table 6** Statistical analysis of topographical landscape attributes of the types of land-use change patterns (TLCP I–IV)

TLCP	Elevation (m)	Area percentage of different slope classes (%)		
	Median	>25°	15°–25°	<15°
I	1,119	12.8	39.2	48.0
II	1,125	11.6	39.1	49.3
III	1,216	10.1	41.2	48.8
IV	1,192	14.1	38.7	47.2

To describe slope in percentage, 15° and 25° equal to 26.8 and 46.6 %, respectively

increased sharply (above $10,000 \text{ t km}^{-2} \text{ year}^{-1}$) in soil retention, which was the highest. The proportions of sharply increased (above $10,000 \text{ t km}^{-2} \text{ year}^{-1}$) area in TLCP II were also above the average, as 7.70 %. In contrast, in TLCP IV villages, 33.04 % of the areas only had a slight increase (below 2,000), and only 0.10 % of the areas had a sharp increase (above $10,000 \text{ t km}^{-2} \text{ year}^{-1}$).

The effects of topographical and meteorological factors

The four TLCPs were characterized by topographical landscape attributes that are shown in Table 6. Although no significant differences were observed in topographical attributes between villages in different TLCPs, due to the special geographical structure, there might exist some connections between physical attributes and villages of different TLCPs.

The TLCP I and IV villages, with a relatively high proportion of steep slopes (12.8 and 14.1 %, respectively), all experienced a large-scale decrease in cropland. In addition, cropland transformed primarily to grassland in the TLCP I villages with low elevations (median value 1,119 m), whereas in the TLCP IV villages with higher elevations (median value 1,192 m), the cropland primarily transformed to shrubland. The TLCP II and III villages, which were featured by a slight decrease in cropland, shared a low proportion of steep slopes (11.6 and 10.1 %, respectively). Additionally, the TLCP III villages, with invariably the highest proportion of forest and shrubland, have the highest elevations (median value 1,216 m). The cropland in villages with a higher proportion of steep slopes tended to have a sharp decrease, whereas the cropland remained relatively stable in villages with a lower proportion of steep slopes. This observation is because the GTGP (the Grain to Green Project) primarily targeted the cropland on steep slopes >25°. In addition, most of the decreased cropland turned into shrubland in villages with higher elevations and into grassland in villages with lower elevations.

However, the spatial heterogeneity of land-use change may not be explained by topographical constraints alone. Other factors must affect this process. The spatial distributions of temperature and precipitation are also noticeable. As shown in Fig. 7, the average temperature did not excessively change; however, a decreasing pattern from the southeast to the northwest was clear. In contrast, the average precipitation decreased from the south (549 mm)

Fig. 7 Average temperature and precipitation from 1981 to 2010

to the north (453 mm). The majority of the TLCP I villages had relatively low temperatures and precipitation, and the TLCP III villages had higher temperatures and precipitation. Climate conditions are usually determining factors for vegetation growth, particularly in arid and semi-arid areas (Fan et al. 2012; Ni et al. 2006; Zhao et al. 2011). However, further analysis is required to reveal the complex relation between land-use changes and meteorological conditions.

Conclusions

Ecological restoration as a large environmental campaign has been growing globally. However, the effectiveness of this growing campaign must be supported by spatially explicit and scientifically informed decision making. In the present research, a general pattern of the abandonment of cultivation at the landscape scale was revealed, where cropland decreased by 21.6 %. Significant spatial variations existed on the village level in the ecological restoration context in the Baota District. The average vegetation cover and soil retention increased by 22.7 and 108 %, respectively, from 2000 to 2010. The income structure of farming households changed dramatically, with the salary income increasing to 30 % of the total income in 2010. The 576 villages were classified into four spatial clusters, which were based on the spatial heterogeneous land-use change patterns, and the landscape pattern, topographical, and climate characteristics of the clusters were characterized. The changes in landscape structural characteristics were

analyzed on different scales, and a major pattern toward a more fragmented and diversified landscape was detected along with spatial variations between villages. The simple landscape-oriented approach to detect the spatial heterogeneity of the land-use change response to ecological restoration may be useful in a variety of contexts because this approach is not so data intensive. Based on the present research findings, it is helpful to consider local scale land use and key landscape function changes, as well as biophysical and landscape pattern factors, for ecological restoration planning and management to achieve high cost efficiency and real-world restoration performance.

Acknowledgements This research was supported by the National Natural Science Foundation of China (No. 41171156), the External Cooperation Program of the Chinese Academy of Sciences (No. GJHZ1215), and K.C. Wong Education Foundation, Hong Kong.

References

- Álvarez Martínez J-M, Suárez-Seoane S, De Luis Calabuig E (2011) Modelling the risk of land cover change from environmental and socio-economic drivers in heterogeneous and changing landscapes: the role of uncertainty. *Landsc Urban Plann* 101(2):108–119. doi:[10.1016/j.landurbplan.2011.01.009](https://doi.org/10.1016/j.landurbplan.2011.01.009)
- Bangash RF, Passuello A, Sanchez-Canales M, Terrado M, López A, Elorza FJ, Ziv G, Acuña V, Schuhmacher M (2013) Ecosystem services in Mediterranean river basin: climate change impact on water provisioning and erosion control. *Sci Total Environ* 458–460:246–255. doi:[10.1016/j.scitotenv.2013.04.025](https://doi.org/10.1016/j.scitotenv.2013.04.025)
- Benini L, Bandini V, Marazza D, Contin A (2010) Assessment of land use changes through an indicator-based approach: a case study from the Lamone river basin in Northern Italy. *Ecol Indic* 10(1):4–14. doi:[10.1016/j.ecolind.2009.03.016](https://doi.org/10.1016/j.ecolind.2009.03.016)

- Bürgi M, Turner MG (2002) Factors and processes shaping land cover and land cover changes along the Wisconsin River. *Ecosystems* 5(2):184–201. doi:[10.1007/s10021-001-0064-6](https://doi.org/10.1007/s10021-001-0064-6)
- Chen L-D, Wang J, Fu B, Qiu Y (2001) Land-use change in a small catchment of northern Loess Plateau. *Agric Ecosyst Environ* 86:163–172
- Chen L, Wei W, Fu B, Lü Y (2007) Soil and water conservation on the Loess Plateau in China: review and perspective. *Prog Phys Geogr* 31(4):389–403. doi:[10.1177/0309133307081290](https://doi.org/10.1177/0309133307081290)
- DeFinis I (2004) eCognition. Software. <http://www.definiens-imaging.com>
- Edwards AWF, Cavalli-Sforza LL (1965) A method for cluster analysis. *Biometrics* 21(2):362–375
- Fan ZM, Li J, Yue TX (2012) Changes of climate-vegetation ecosystem in Loess Plateau of China. *Procedia Environ Sci* 13:715–720. doi:[10.1016/j.proenv.2012.01.064](https://doi.org/10.1016/j.proenv.2012.01.064)
- Feng J, Wang T, Qi S, Xie C (2004) Land degradation in the source region of the Yellow River, northeast Qinghai-Xizang Plateau: classification and evaluation. *Environ Geol* 47(4):459–466. doi:[10.1007/s00254-004-1161-6](https://doi.org/10.1007/s00254-004-1161-6)
- Fischer G, Nachtergaele F, Prieler S, Van Velthuisen H, Verelst L, Wiberg D (2008) Global agro-ecological zones assessment for agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy
- Fu B, Liu Y, Lü Y, He C, Zeng Y, Wu B (2011) Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. *Ecol Complex* 8(4):284–293. doi:[10.1016/j.ecocom.2011.07.003](https://doi.org/10.1016/j.ecocom.2011.07.003)
- Harris JA (2003) Measurements of the soil microbial community for estimating the success of restoration. *Eur J Soil Sci* 54(4):801–808. doi:[10.1046/j.1351-0754.2003.0559.x](https://doi.org/10.1046/j.1351-0754.2003.0559.x)
- Hietel E, Waldhardt R, Otte A (2004) Analysing land-cover changes in relation to environmental variables in Hesse, Germany. *Landsc Ecol* 19(5):473–489. doi:[10.1023/B:LAND.0000036138.82213.80](https://doi.org/10.1023/B:LAND.0000036138.82213.80)
- Hobbs RJ, Harris JA (2001) Restoration ecology: repairing the earth's ecosystems in the new millennium. *Restor Ecol* 9(2):239–246. doi:[10.1046/j.1526-100x.2001.009002239.x](https://doi.org/10.1046/j.1526-100x.2001.009002239.x)
- Huang L, Shao Q, Liu J (2012) Forest restoration to achieve both ecological and economic progress, Poyang Lake basin, China. *Ecol Eng* 44:53–60. doi:[10.1016/j.ecoleng.2012.03.007](https://doi.org/10.1016/j.ecoleng.2012.03.007)
- Janssen LLF, Wel FJMV (1994) Accuracy assessment of satellite derived land-cover data: a review, vol 4. American Society for Photogrammetry and Remote Sensing, Bethesda, MD, ETATS-UNIS
- Leigh P (2005) The ecological crisis, the human condition, and community-based restoration as an instrument for its cure. *Ethics Sci Environ Politics* 2005:3–15
- Liu J, Li S, Ouyang Z, Tam C, Chen X (2008) Ecological and socioeconomic effects of China's policies for ecosystem services. *Proc Natl Acad Sci* 105(28):9477–9482. doi:[10.1073/pnas.0706436105](https://doi.org/10.1073/pnas.0706436105)
- Liu D, Li B, Liu X, Warrington DN (2011) Monitoring land use change at a small watershed scale on the Loess Plateau, China: applications of landscape metrics, remote sensing and GIS. *Environ Earth Sci* 64(8):2229–2239. doi:[10.1007/s12665-011-1051-7](https://doi.org/10.1007/s12665-011-1051-7)
- Lü Y, Fu B, Wei W, Yu X, Sun R (2011) Major ecosystems in China: dynamics and challenges for sustainable management. *Environ Manage* 48(1):13–27. doi:[10.1007/s00267-011-9684-6](https://doi.org/10.1007/s00267-011-9684-6)
- Lü Y, Fu B, Feng X, Zeng Y, Liu Y, Chang R, Sun G, Wu B (2012) A policy-driven large scale ecological restoration: quantifying ecosystem services changes in the Loess Plateau of China. *PLoS ONE* 7(2):e31782. doi:[10.1371/journal.pone.0031782](https://doi.org/10.1371/journal.pone.0031782)
- Lufafa A, Tenywa MM, Isabirye M, Majaliwa MJG, Woomer PL (2003) Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soil Loss model. *Agric Syst* 76(3):883–894. doi:[10.1016/s0308-521x\(02\)00012-4](https://doi.org/10.1016/s0308-521x(02)00012-4)
- McGarigal K, Cushman S, Ene E (2012) FRAGSTATS v4: spatial pattern analysis program for categorical and continuous maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. <http://www.umass.edu/landeco/research/fragstats/fragstats.html>
- Moore MM, Covington WW, Fule PZ (1999) Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. *Ecol Appl* 9(4):1266–1277
- Munroe DK, Müller D (2007) Issues in spatially explicit statistical land-use/cover change (LUCC) models: examples from western Honduras and the Central Highlands of Vietnam. *Land Use Policy* 24(3):521–530. doi:[10.1016/j.landusepol.2005.09.007](https://doi.org/10.1016/j.landusepol.2005.09.007)
- Ni J, Harrison SP, Colin Prentice I, Kutzbach JE, Sitch S (2006) Impact of climate variability on present and Holocene vegetation: a model-based study. *Ecol Model* 191(3–4):469–486. doi:[10.1016/j.ecolmodel.2005.05.019](https://doi.org/10.1016/j.ecolmodel.2005.05.019)
- Pineda Jaimes NB, Bosque Sendra J, Gómez Delgado M, Franco Plata R (2010) Exploring the driving forces behind deforestation in the state of Mexico (Mexico) using geographically weighted regression. *Appl Geogr* 30(4):576–591. doi:[10.1016/j.apgeog.2010.05.004](https://doi.org/10.1016/j.apgeog.2010.05.004)
- Qi X, Wang K, Zhang C (2013) Effectiveness of ecological restoration projects in a karst region of southwest China assessed using vegetation succession mapping. *Ecol Eng* 54:245–253. doi:[10.1016/j.ecoleng.2013.01.002](https://doi.org/10.1016/j.ecoleng.2013.01.002)
- Reid R, Kruska R, Muthui N, Taye A, Wotton S, Wilson C, Mulatu W (2000) Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. *Landsc Ecol* 15(4):339–355. doi:[10.1023/A:1008177712995](https://doi.org/10.1023/A:1008177712995)
- Ren Y, Wei X, Wang D, Luo Y, Song X, Wang Y, Yang Y, Hua L (2013) Linking landscape patterns with ecological functions: a case study examining the interaction between landscape heterogeneity and carbon stock of urban forests in Xiamen, China. *For Ecol Manage* 293:122–131. doi:[10.1016/j.foreco.2012.12.043](https://doi.org/10.1016/j.foreco.2012.12.043)
- Singh K, Pandey VC, Singh B, Singh RR (2012) Ecological restoration of degraded sodic lands through afforestation and cropping. *Ecol Eng* 43:70–80. doi:[10.1016/j.ecoleng.2012.02.029](https://doi.org/10.1016/j.ecoleng.2012.02.029)
- Su C, Fu B, Wei Y, Lü Y, Liu G, Wang D, Mao K, Feng X (2012) Ecosystem management based on ecosystem services and human activities: a case study in the Yanhe watershed. *Sustain Sci* 7(1):17–32. doi:[10.1007/s11625-011-0145-1](https://doi.org/10.1007/s11625-011-0145-1)
- Sun Q, Wu Z, Tan J (2011) The relationship between land surface temperature and land use/land cover in Guangzhou, China. *Environ Earth Sci* 65(6):1687–1694. doi:[10.1007/s12665-011-1145-2](https://doi.org/10.1007/s12665-011-1145-2)
- Sutherland WJ (2002) Restoring a sustainable countryside. *Trends Ecol Evol* 17(3):148–150. doi:[10.1016/S0169-5347\(01\)02421-1](https://doi.org/10.1016/S0169-5347(01)02421-1)
- Syrbe R-U, Bastian O, Röder M, James P (2007) A framework for monitoring landscape functions: The Saxon Academy Landscape Monitoring Approach (SALMA), exemplified by soil investigations in the Kleine Spree floodplain (Saxony, Germany). *Landsc Urban Plann* 79(2):190–199. doi:[10.1016/j.landurbplan.2006.02.005](https://doi.org/10.1016/j.landurbplan.2006.02.005)
- Uuemaa E, Mander Ü, Marja R (2013) Trends in the use of landscape spatial metrics as landscape indicators: a review. *Ecol Ind* 28:100–106. doi:[10.1016/j.ecolind.2012.07.018](https://doi.org/10.1016/j.ecolind.2012.07.018)
- Vishnudas S, Savenije HHG, Zaag PVd (2012) Watershed development practices for ecorestoration in a tribal area—a case study in Attappady hills, South India. *Phys Chem Earth Parts A/B/C* 47–48:58–63. doi:[10.1016/j.pce.2012.04.001](https://doi.org/10.1016/j.pce.2012.04.001)
- Wang X, Lu C, Fang J, Shen Y (2007) Implications for development of grain-for-green policy based on cropland suitability evaluation

- in desertification-affected north China. *Land Use Policy* 24(2):417–424. doi:[10.1016/j.landusepol.2006.05.005](https://doi.org/10.1016/j.landusepol.2006.05.005)
- Wischmeier WH, Smith DD (1965) Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: guide for selection of practices for soil and water conservation, vol 282. Agricultural Research Service, US Department of Agriculture
- Wischmeier WH SD (1978) Predicting rainfall erosion losses: a guide to conservation planning. In: *Agricultural research services handbook*, vol 537. US Department of Agriculture (USDA), Washington, DC, p 57
- Xu Y, Yang B, Tang Q (2008) Influences of land use change on agricultural development in the Middle Loess Plateau. *Res Soil Water Conser* 15(2):4–8
- Ye C, Li C-H, Yu H-C, Song X-F, Zou G-Y, Liu J (2011) Study on ecological restoration in near-shore zone of a eutrophic lake, Wuli Bay, Taihu Lake. *Ecol Eng* 37(9):1434–1437. doi:[10.1016/j.ecoleng.2011.03.028](https://doi.org/10.1016/j.ecoleng.2011.03.028)
- Yin R, Yin G (2009) China's ecological restoration programs: initiation, implementation, and challenges. In: *An integrated assessment of china's ecological restoration programs*. Springer, Netherlands, pp 1–19. doi:[10.1007/978-90-481-2655-2_1](https://doi.org/10.1007/978-90-481-2655-2_1)
- Yong X, Qing T, Dingguo M, Tengyun G (2006) De-farming and ecological restoration in the loess hilly-gully region in northern China. *J Mt Sci* 3(2):168–177
- Zhang Y, Z-z Gao (2008) Reflection on consolidating the achievement of returning cropland to forestry in Yanan City. *J Yanan Coll Educ* 2:008
- Zhang K, Li S, Peng W, Yu B (2004a) Erodibility of agricultural soils on the Loess Plateau of China. *Soil Tillage Res* 76(2):157–165. doi:[10.1016/j.still.2003.09.007](https://doi.org/10.1016/j.still.2003.09.007)
- Zhang Q-J, Fu B-J, Chen L-D, Zhao W-W, Yang Q-K, Liu G-B, Gulinck H (2004b) Dynamics and driving factors of agricultural landscape in the semiarid hilly area of the Loess Plateau, China. *Agric Ecosyst Environ* 103(3):535–543. doi:[10.1016/j.agee.2003.11.007](https://doi.org/10.1016/j.agee.2003.11.007)
- Zhang G, Dong J, Xiao X, Hu Z, Sheldon S (2012) Effectiveness of ecological restoration projects in Horqin Sandy Land, China based on SPOT-VGT NDVI data. *Ecol Eng* 38(1):20–29. doi:[10.1016/j.ecoleng.2011.09.005](https://doi.org/10.1016/j.ecoleng.2011.09.005)
- Zhao X, Tan K, Zhao S, Fang J (2011) Changing climate affects vegetation growth in the arid region of the northwestern China. *J Arid Environ* 75(10):946–952. doi:[10.1016/j.jaridenv.2011.05.007](https://doi.org/10.1016/j.jaridenv.2011.05.007)
- Zhou D, Zhao S, Zhu C (2012) The Grain for Green Project induced land cover change in the Loess Plateau: a case study with Ansai County, Shanxi Province, China. *Ecol Ind* 23:88–94. doi:[10.1016/j.ecolind.2012.03.021](https://doi.org/10.1016/j.ecolind.2012.03.021)
- Zucca C, Pulido-Fernández M, Fava F, Dessena L, Mulas M (2013) Effects of restoration actions on soil and landscape functions: *Atriplex nummularia* L. plantations in Ouled Dlim (Central Morocco). *Soil Tillage Res* 133:101–110. doi:[10.1016/j.still.2013.04.002](https://doi.org/10.1016/j.still.2013.04.002)