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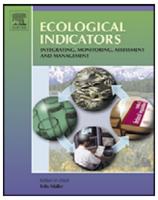

Original Article

The Grain for Green Project induced land cover change in the Loess Plateau: A case study with Ansai County, Shanxi Province, China

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ABSTRACT

The Grain for Green Project (GGP) is the largest land retirement/afforestation program in China; it was primarily initiated to reduce the soil erosion and improve the ecological conditions in the Loess Plateau in 1999. If effective, this massive regional effort will induce significant improvement in the vegetation conditions. At this time, the effectiveness of the GGP has not been well documented. Using Ansai County as a case study, we characterized the impact of the GGP on the land covers and landscape characteristics of this area by using multi-temporal Landsat MSS, TM and ETM+ images of 1978, 1990, 1995, 2000, 2005 and 2010. The results indicate that the land cover patterns and landscape characteristics in the county were greatly altered in a considerably short period. The implementation of the GGP increased the newly forested land substantially to 21.4% of the study area by 2010 at the cost of both cropland and shrub–grassland, which decreased by 46.3% and 18.8%, respectively, from 1995 to 2010. Consequently, the coverage of forested land (both older forest and newly forested land) increased from 12.4% in 1995 to 37.7% in 2010. Moreover, the GGP increased landscape fragmentation as indicated by a decreasing mean patch size and changes in class-level landscape indicators varied with land cover categories. The GGP induced improvement in vegetation conditions may benefit soil erosion alleviation and carbon sequestration in the Loess Plateau. However, the potential for the GGP to provide long-term positive ecological effects requires further study.

1. Introduction

The Earth's land surface has been greatly altered by human activities (Vitousek et al., 1997) with abrupt changes primarily caused by governmental policy transformations (Lambin et al., 2001). China's economy is growing at the fastest rate of any of the major nations, but at the cost of worsening environments (Liu and Diamond, 2008); this is evidenced by grassland degradation, desertification, and soil erosion that have already seriously affected the sustainable development in China (Ding, 2003). In order to address these environmental problems and improve human well-being, China has undertaken several major ecological restoration projects in recent years; of these, the Grain for Green Project (GGP) (also called the Sloping Land Conversion Program), initiated in 1999, is the largest (Wang et al., 2007a; Liu et al., 2008). The GGP advocates three types of land conversions: cropland to forest, cropland to grassland, and wasteland to forest. About 28 million hectares of cropland were converted to forests from 1999 to 2009 according to agricultural census data (see http://politics.people.com.cn/GB/1026/12477229.html as at 2011-2-11) and an additional "soft" goal of afforesting a roughly equal area of wasteland was set. This will inevitably result in large-scale, transformational changes and profound environmental impacts both regionally and nationally (Wang et al., 2007b). However, the impact of the GGP has not been well documented. Since land cover dynamics is the central issue in the study of global environmental change (Fischer and Sun, 2001; Verburg et al., 2011), it is imperative to first address the impacts of the GGP on land cover change to better understand and assess the effectiveness of large-scale restoration efforts at both regional and national scales.

The Loess Plateau, a priority region for the GGP, is located in the upper and middle reaches of the Yellow River and is well-known for its severe soil erosion and water loss (McVicar et al., 2007) largely due to improper anthropogenic land use activities such as overcultivation of marginal lands, overgrazing, and over-deforestation (Shi and Shao, 2000; Chen et al., 2007). Although a large amount of resources was invested into the GGP, its effectiveness on land cover change and ecological restoration is largely unknown. For example, the establishment and development of new forests was a major concern (Cao et al., 2010). Here we selected Ansai County on the Loess Plateau as a case study to quantify and assess the impacts of the GGP on land cover and landscape characteristics, and, therefore, the effectiveness of the GGP using multi-temporal Landsat images.

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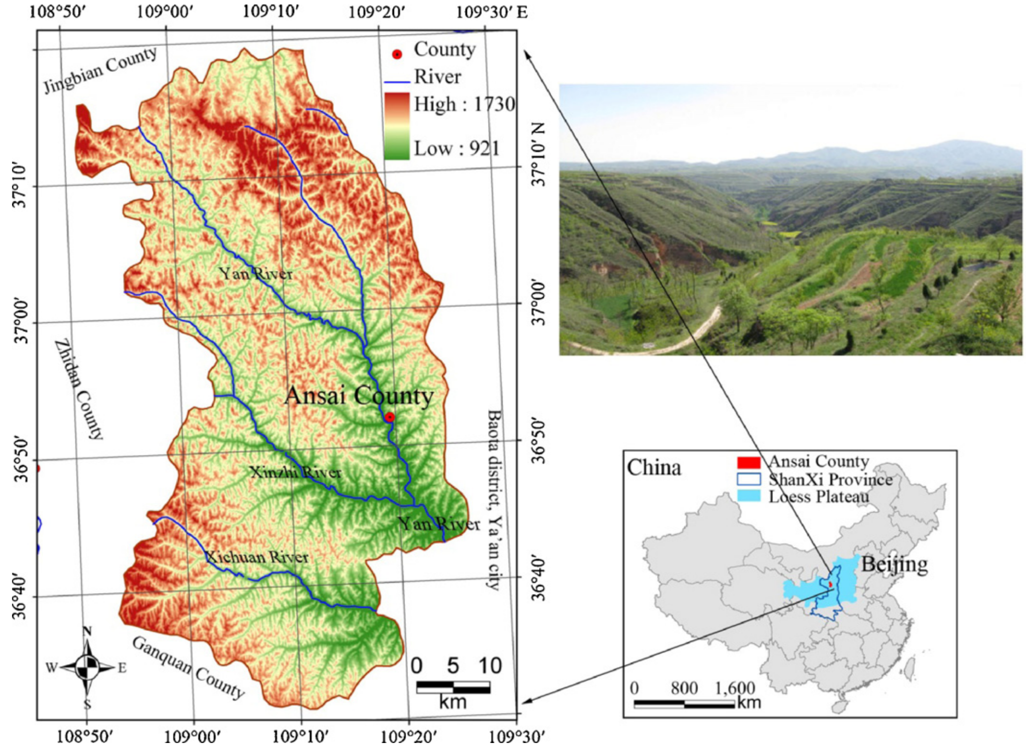

Fig. 1. Location of study area. DEM in the study area was obtained from the ASTER GDEM (download via the Internet from http://www.gdem.aster.ersdac.or.jp/search.jsp), and the landscape picture was taken by Li in 2006 (Li and Pang, 2010).

2. 2 Data and methods

2.1. Study area

Ansai County is located in the central part of the Loess Plateau (40°14′11″N–42°27′42″N, 75°33′16″E to 80°59′7″E) and covers an area of 2940.9 km^2 (Fig. 1). It has the typical hilly loess terrain of the Loess Plateau with varying altitudes between 921 and 1730 m a.s.l. and a semi-arid climate with mean annual precipitation of 520 mm and mean temperature of 8.6 °C. The study area was mainly covered with shrub–grasslands and slope croplands before the GGP (Fu et al., 2006). Due to the steep terrains, most cropland of the county is not or only marginally suitable for cropping. Lu and van Ittersum (2004) reported that more than 70% of the total cropland area in 2000 had a slope gradient of more than 18°. Non-native tree species such as *Robinia pseudoacacia*, *Prunus armeniaca*, *Hippophae rhamnoides*, *Platycladus orientalis*, and *Caragana korshinskii* were predominantly used in the study area under the GGP (Cao et al., 2009). *R. pseudoacacia* is the most popular species planted in Ansai County as it can resist stronger drought stress. About 80% of the new forests were created for ecological purposes without explicitly considering short-term economic benefits (Liu et al., 2010).

2.2. Land cover information

While our main focus was on the impacts of the GGP, we set the time frame of this study from 1970s to present to cover several other changes in land use policy that were put in place in Ansai County during the Landsat era (e.g., the 1978 "Household Responsibility System" and the 1992 "Market-directed Economic System", see Fu et al., 2006). Looking back further in history to the late 1970s, when Landsat images became first available, would enable us to reconstruct a longer history of land cover change and analyze the effectiveness of the GPP relative to other land use change policies. Based on data availability in the study area and similar land cover change studies in other parts of the world (e.g., Loveland et al., 2002), we selected images from six years (i.e., 1978, 1990, 1995, 2000, 2005 and 2010) to characterize the temporal change of land cover for this study.

The data sources used to acquire land cover information include Landsat MSS (bands 1–4), TM (bands 2, 3, 4, 5 and 7), and ETM+ (bands 2, 3, 4, 5 and 7) data (http://www.usgs.gov/ and http://datamirror.csdb.cn/) (Table 1). First, the MSS images were re-sampled to the resolution of 30 × 30 m, and all the images were geo-referenced to those from 2000. Then the data were preprocessed (e.g., re-projection, mosaic, histogram equalization) using ERDAS Imagine version 9.1. Albers Conical Equal Area was used as the re-projection coordinate system.

The land covers were grouped into six types according to the characteristics of the spectral reflectance and the objectives of the analysis: cropland, forest, newly forested land, shrub–grassland, built-up land, and water body (Table 2) using the maximum likelihood classification approach (Strahler, 1980). We also integrated the histogram-equalized NDVI (derived from the Landsat images)

Table 1
Data sources for land cover classification used in this study.

Landsat path/row (WRS2)	Period (Year-mouth-day)					
	1978	1990	1995	2000	2005	2010
127/34	1978-08-01	1990-08-29	1995-05-07	2000-09-01	2005-07-13	2010-10-15
127/35		1992-07-17	1995.05-07	2000-06-29	2005-07-13	2010-09-13

Table 2
Descriptions for land cover types in Ansai County.

Land cover type	General description
Cropland	The lands used for crop planting, including paddy field, irrigated land and upland. The irrigation ditches, farm–machine roads and other service lands are also included in this group. Most croplands is not or only marginally suitable for cultivation.
Forest	Lands where natural or planted forests with a canopy density >30% (including Orchards and shelter–forest lands).
Newly forested land	Reforested/afforested land converted from the cropland and wasteland after the implementation of the GGP which is not growing well to be seen as forest.
Shrub–grassland	Lands mainly covered by herbaceous plant or by natural sparsely shrubs. The wasteland was included in this group.
Built-up land	Consisted of cities, towns (lands used for townships and settlement), and industrial and mining lands.
Water body	Reservoirs and ponds, rivers and flooded lands, and the beach.

with the slope that was derived from the ASTER GDEM (downloaded from http://www.gdem.aster.ersdac.or.jp/search.jsp) into our classification. This approach has often been regarded as a more effective method for land cover change detection as it can enhance the difference among spectral features and suppress topographic and shade effects (Pedroni, 2003; Saha et al., 2005).

The accuracies of the classified products were assessed by using Google Earth Pro® (GE), which is a practical means to validate land cover classification results (Luedeling and Buerkert, 2008). GE displays satellite images, maps, and other geographic information of the Earth's surface, and most land areas are covered by satellite imagery with a resolution of about 15 × 15 m. Additionally, field photos uploaded to Panoramio (http://www.panoramio.com/) were also used to assess the accuracy, as they are effective in distinguishing among different land cover types. However, there was no information available for us to validate the classification results before 2007 as the high resolution images in GE covering the study area are acquired within the last four years. Thus, we used the Spot images (acquired in 2010) in GE to validate (1) the classification results of 2010, and (2) the classification results before 2010 in the areas only where land cover remained unchanged from 1978 to 2010. In carrying the validation procedure, we first created two sets of 500 points that were randomly drawn from the classification results of 2010 and the unchanged areas from 1978 to 2010, respectively. Then, these points were imported into GE and superimposed over the Spot images for accuracy assessment. Finally, the Kappa coefficients measuring classification accuracy (Foody, 2002) were calculated. Results showed that the Kappa coefficients were 0.83 for the classification results of 2010 and 0.79 for the results before 2010, respectively; these values met the accuracy requirement of land cover change evaluation (Janssen and van der Wel, 1994).

2.3. Land cover change

Based on the classified products, the land cover changes from 1978 to 2010 were analyzed by the area and the area change of each land cover type between two periods. Land cover transition and contribution matrix were generated to reveal the detailed land cover transformations for the five time intervals from 1978 to 2010.

2.4. Structural metrics of landscape

Landscape metrics or indices are frequently used to assess the structural characteristics of the landscape and to monitor changes in land use/cover (Thielen et al., 2008; Benini et al., 2010; Benedek et al., 2011). We exported the classification maps to Fragstats 3.3 software (McGarigal et al., 2002) to calculate the following three landscape metrics for each of the six land cover maps: area percentage of land cover, number of patches, and mean patch size (MPS) at both class (each land cover type) and landscape (the entire study area) levels. Because a smaller MPS might be considered more fragmented, MPS can serve as a fragmentation index of habitat at both the class and landscape level (Turner, 1990). The calculation of the first two metrics is straightforward, and MPS was calculated as

$$\mathrm{MPS} = \sum_{j=1}^{n} \frac{a_{ij}}{n_i}$$

where i is the ith land cover type, j is the jth patch of the ith land cover type, a_{ij} is the jth patch area (ha) of the ith land cover type, and n_i is the patch numbers of the ith land cover type. We did not analyze the changes of the built-up land and the water body since their areas were very small and GGP exerted little influence on them.

3. Results

3.1. Land cover changes

The GGP has drastically altered the land cover patterns in Ansai County (Fig. 2 and Table 3). Before the implementation of the GGP in 1999, cropland increased from 945.3 km^2 in 1978 to 1092.1 km^2 in 1990, and then stabilized to 1078.2 km^2 in 1995. Concurrently, shrub–grassland experienced a moderate decline from 1978 to 1990 and then leveled off in 1995. In contrast, forest increased slightly after a decrease during the period 1978–1990. After the implementing of the GGP, newly forested land elevated substantially. Overall, cropland decreased sharply by 46.3%, shrub–grassland decreased by 18.8%, and forested land (both older forest and newly forested land) increased by 204.4% from 1995 to 2010.

3.2. Land cover transitions

A transition matrix (Table 4) was calculated to help understand the land cover conversion among land cover types between two neighboring periods. The increase of cropland between 1978 and 1990 was primarily contributed by the conversions from shrub–grassland and forest, which accounted for 30.3% and 5.4% of the coverage of cropland in 1990, respectively. From 1990 to 1995, the conversions reversed, resulting in a slight decrease in cropland. Since 1995, cropland decreased rapidly primarily due to its conversion to newly forested land (contributed 31.9% and 9.6% to the coverage of the newly forested land in 2005 and 2010, respectively). Concurrently, the conversion from shrub–grassland to newly forested land was also significant (accounting for 8.7%, 14.5%, and 26.0% of the coverage of shrub–grassland in 1995, 2000 and 2005, respectively). These two land conversions (i.e., cropland to forest and shrub–grassland to forest) were the two main types of land transformation induced by the GGP.

3.3. Change of landscape characteristics

The GGP has significantly modified landscape characteristics in Ansai County (Figs. 2(g and h) and 3). It created a more fragmented landscape as evidenced by the increase of total number of patches and decrease of the MPS (Fig. 3c).

The changes in class-level landscape characteristics varied with land cover category (Figs. 2h and 3). The area percentage of cropland decreased significantly from 36.7% in 1995 to 19.7% in 2010, after

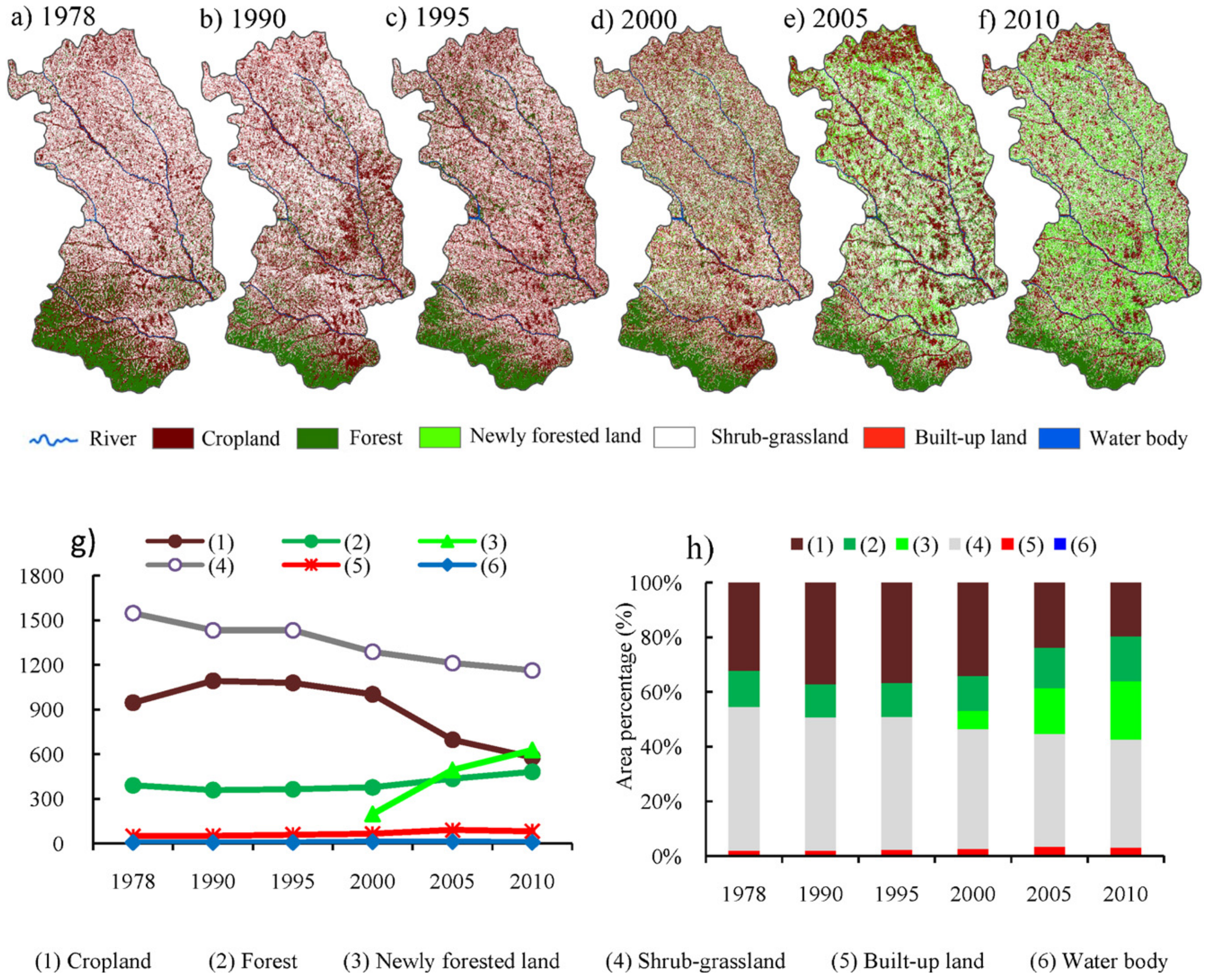

Fig. 2. The distribution and composition of land covers in the study area for six periods. (a) 1978, (b) 1990, (c) 1995, (d) 2000, (e) 2005, (f) 2010, (g) areas of land cover types and (h) their cumulative histogram by percentage. GGP: Grain for Green Project.

Table 3
Land cover changes in Ansai County.

Land cover types		Cropland	Forest	Newly Forested land	Shrub–grassland	Built-up land	Water body
Area (km^2)	1978	945.3	391.1		1547.4	49.6	7.1
	1990	1092.1	358.2		1432.0	51.1	7.2
	1995	1078.2	364.3		1432.2	58.9	6.8
	2000	1001.5	377.3	197.8	1287.0	65.3	11.6
	2005	696.7	434.6	494.1	1212.2	90.7	12.4
	2010	578.6	481.1	627.9	1162.8	82.2	8.0
Change in 1978–1990	Area (km^2)	146.8	−32.9		−115.4	1.5	0.0
	Rate (%)	15.5	−8.4		−7.5	3.1	0.6
Change in 1990–1995	Area (km^2)	−13.9	6.1		0.3	7.8	−0.3
	Rate (%)	−1.3	1.7		0.0	15.4	−4.6
Change in 1995–2000	Area (km^2)	−76.7	13.0	197.8	−145.3	6.4	4.8
	Rate (%)	−7.1	3.6		−10.1	10.9	70.3
Change in 2000–2005	Area (km^2)	−304.8	57.2	296.3	−74.8	25.3	0.8
	Rate (%)	−30.4	15.2	149.8	−5.8	38.8	6.8
Change in 2005–2010	Area (km^2)	−118.1	46.5	133.8	−49.4	−8.5	−4.4
	Rate (%)	−17.0	10.7	27.1	−4.1	−9.3	−35.3
Change in 1995–2010	Area (km^2)	−499.7	116.8	627.9	−269.5	23.3	1.2
	Rate (%)	−46.3	32.1		−18.8	39.5	17.6
Change in 1978–2010	Area (km^2)	−366.8	90.0		−384.7	32.7	0.9
	Rate (%)	−38.8	23.0		−24.9	65.9	12.8

Table 4
Land cover transition and contribution rate (*a*% and *b*%) between 1978 and 2010.

Land cover types	CL		FR		NFL		SGL		BUL		WB	
	a	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*	*a*	*b*
1978–1990												
CL	69.8	64.2	2.6	6.9			27.0	17.1	0.4	7.6	0.2	25.9
FR	14.1	5.4	63.2	69.1			22.5	5.9	0.2	1.7	0.0	0.4
SGL	20.1	30.3	5.5	23.8			74.2	76.7	0.1	2.9	0.1	23.4
BUL	1.3	0.1	1.0	0.1			8.8	0.3	88.7	86.0	0.2	1.5
WB	23.0	0.2	5.0	0.1			9.3	0.0	13.3	1.9	49.4	48.8
1990–1995												
CL	70.7	67.4	8.4	19.8			20.8	15.7	0.1	2.1	0.0	0.1
FR	15.1	5.0	59.1	48.5			24.0	6.3	1.6	9.9	0.2	8.1
SGL	19.7	27.4	9.2	31.6			70.7	77.7	0.4	9.2	0.1	10.9
BUL	2.5	0.1	0.4	0.1			6.1	0.2	91.0	78.6	0.1	0.5
WB	6.6	0.0	1.5	0.0			13.3	0.1	1.9	0.2	76.8	80.4
1995–2000												
CL	79.3	85.4	4.6	13.1	7.4	39.9	8.3	7.0	0.0	0.8	0.4	35.8
FR	14.0	6.1	69.4	80.1	0.0	0.0	16.5	5.6	0.0	0.2	0.1	2.5
SGL	5.9	8.0	1.9	6.8	8.7	59.7	82.6	87.3	0.8	17.1	0.1	12.0
BUL	6.2	0.4	0.6	0.1	1.0	0.3	0.1	0.0	90.2	81.7	2.0	10.1
WB	14.2	0.1	1.5	0.0	0.1	0.0	16.5	0.1	1.7	0.2	66.0	39.6
2000–2005												
CL	66.4	95.3	0.7	1.5	15.7	31.9	14.6	12.0	2.4	26.9	0.1	10.7
FR	3.4	1.8	80.5	70.0	1.9	1.4	13.7	4.3	0.4	1.8	0.1	1.9
NFL	8.6	2.5	5.3	2.4	71.9	28.9	13.9	2.3	0.2	0.4	0.0	0.4
SGL	0.1	0.2	8.6	25.5	14.5	37.7	76.2	80.9	0.3	5.0	0.3	26.3
BUL	0.8	0.1	1.7	0.3	0.1	0.0	7.2	0.4	88.8	64.2	1.4	7.4
WB	7.0	0.1	9.9	0.3	2.7	0.1	9.5	0.1	13.8	1.8	57.2	53.2
2005–2010												
CL	77.9	93.8	3.7	5.3	8.6	9.6	8.6	5.2	1.2	9.8	0.1	5.2
FR	5.7	4.3	72.7	65.5	0.1	0.1	21.0	7.8	0.5	2.5	0.0	1.0
NFL	1.9	1.6	7.7	7.8	50.4	39.6	39.8	16.9	0.2	1.0	0.0	0.7
SGL	0.0	0.1	8.3	21.0	26.0	50.2	65.0	67.9	0.6	8.6	0.0	1.3
BUL	0.4	0.1	2.1	0.4	3.0	0.4	26.0	2.0	68.5	75.6	0.0	0.1
WB	2.7	0.1	1.9	0.0	1.8	0.0	17.4	0.2	16.1	2.4	60.1	91.7

a: Transition rate is the area percentage of a transition type (e.g. CL to FR) between two neighboring periods based on the area of certain land cover (e.g. CL) in the beginning period.
b: Contribution rate is the area percentage of a transition type (e.g. CL to FR) between two neighboring periods based on the area of certain land cover (e.g. FR) in the ending period
Land cover types abbreviations: CL, cropland; FR, forest; NFL, newly forested land; SGL, shrub–grassland; BUL, built-up land; WB, water body.

a slight increase in 1978–1990. Shrub–grassland decreased from 52.6% in 1978 to 39.5% in 2010. In contrast, the newly forested land increased greatly from 6.7% in 2000 to 21.4% in 2010, and forest increased from 12.4% in 1995 to 16.4% in 2010.

The MPS of the cropland increased from 4.5 ha in 1978 to 5.7 ha in 1995 primarily due to the continuous increase in the cropland area along with the decrease in the number of patches, and the MPS decreased drastically to 3.0 ha in 2010 owing to significant area loss after the GGP (Figs. 2g and 3). Comparatively, the MPS of forest decreased from 4.7 ha in 1978 to 2.2 ha in 2010 largely driven by a rising number of patches (from 8213 in 1978 to 21,445 in 2010), and a similar trend was observed in shrub–grassland. Both the area and the MPS of newly forested land elevated greatly after the implementation of the GGP, and its number of patches remained the largest among all land cover types after the GGP.

4. Discussions

Our classification results agreed well with the census data although we did not refer to these statistics during our

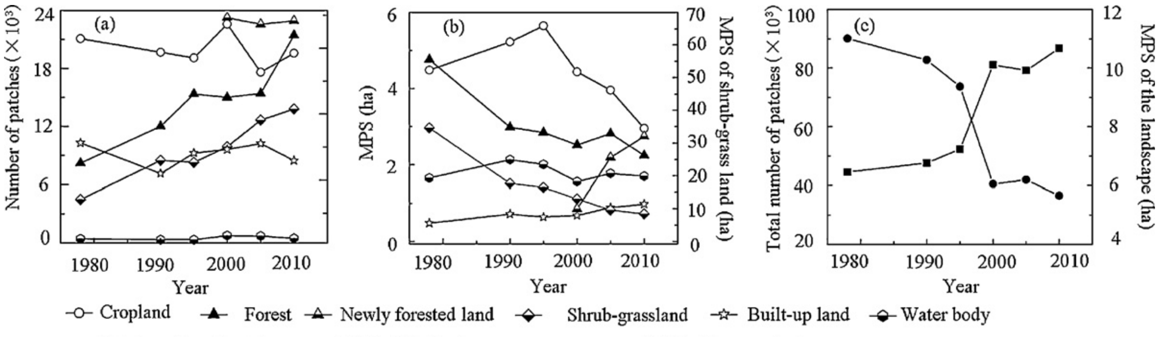

Fig. 3. Number of patches (a), mean patch size for the land cover types (b), and the total number of patches together with the mean patch size for the landscape in 1978, 1990, 1995, 2000, 2005 and 2010.

classification processes. According to the governmental statistics (see http://www.sxny.gov.cn/Html/2005-9-13/2_1847_2005-9-13_3772. html as at 2011-6-12), Ansai County had converted an area of 678.4 km^2 sloping land from 1999 to 2005; this is larger than that of the newly forested land detected in 2005 (494.1 km^2), but very close to that in 2010 (627.9 km^2) detected from the present study. Given the time needed for planted seedlings to become young forests and, therefore, detectable by remote sensing (~5 years), we can see that change in forested area detected by remote sensing from 1995 to 2010 agreed well with the government report from 1995 to 2005. Cropland areas in the statistics were 1190, 970, and 710 km^2 in 1990, 2000, and 2005, respectively (Hu and Ma, 2008), which were also close to the areas detected from remote sensing of this study (Table 3). Another consequence in the delay of picking up the newly forested areas effectively using remote sensing is that the newly forested area might be subject to large uncertainty especially for forests younger than 5 years, and they are likely mixed with the shrub–grassland category as other land covers can easily be distinguished.

The regional and national policies had various impacts on land cover change in the study area. In 1978, the Chinese government adopted a new nationwide land policy called the "Household Responsibility System"; under this policy land-use rights were granted to individuals in the rural areas, creating tremendous economic incentives. In the study area, farmers were allowed to reclaim some marginal lands; this change was the main contribution to the slight increase in cropland in 1978–1990 (Fu et al., 2006). Since 1992, the "Market-Directed Economic System" replaced the planned economic system, and the agricultural sector was once again adjusted from mainly cropping to a diverse portfolio including stock raising, economic crop planting, and orchard. Consequently, a portion of sloping cropland was replaced gradually by pasture and forested land (Fu et al., 2006). In addition, owing to the accelerated land degradation, the government encouraged tree planting in nonproductive rangeland (Shi and Shao, 2000; Chen et al., 2007). Nevertheless, our results indicated that the implementation of the two policies prior to the GGP had small impacts on the change of land cover in the region as compared with those of the GGP. With the GGP, cropland decreased from 36.7% to 19.7% (in terms of total area) and shrub–grassland from 52.6% to 39.5%, while forestland (older and new together) increased from 12.4% to 37.8% from 1995 to 2010.

In addition, the GGP induced a more fragmented landscape; this can be attributed mainly to the abrupt increase in the number of patches of newly forested land. Changes in class-level landscape characteristics varied significantly among different land cover types. Forest and shrub–grassland became more fragmented after the GGP as suggested by the increased number of small forest patches and decreased mean patch size of shrub–grassland. This was a direct result of the silvicultural practices in the region where trees were favorably planted on shady hilly slopes while shrubs or grasses were planted on dry sunny slopes (Wang, 2006); this action broke larger pieces of crop or shrub–grassland prior to the GGP. In contrast, the fragmentation of cropland transformed from a decreasing into a rising trend.

Alleviating soil erosion was the primary goal of the GGP launched in the Loess Plateau; in this area, it is well known that soil erosion was negatively correlated with vegetation condition, especially forest coverage (Zhou et al., 2006; Li et al., 2006). As shown in this study, the GGP enhanced the forest coverage (older forest and newly forested land) from 12.4% in 1995 to 37.7% in 2010 (Fig. 2h). Evidence shows that soil erosion in the Loess Plateau was reduced by 38.8% on average from 1999 to 2006 (Li et al., 2010), which might be partly attributed to the increase in forest coverage induced by the GGP.

In areas where cultivated land was converted to forest both living biomass and soil organic matter are expected to increase (Watson et al., 2000; Chang et al., 2011). Similar results were observed in the Loess Plateau where soil organic carbon increased by 76% 23 years after the reforestation of cropland (Li and Pang, 2010; Chang et al., 2011); this suggests that the GGP-induced land cover changes can potentially lead to carbon sequestration in both vegetation and soils and much-needed enhanced soil fertility for the region.

One of the major concerns of the GGP was its potential impact on water resources in affected regions. In areas with adequate precipitation, conversion of croplands and grasslands to forests might improve or have little impact on regional water conditions (Schume et al., 2004). On the other hand, large-scale afforestation in arid and semi-arid regions, such as the Loess Plateau, may increase the severity of water shortage (Tenry et al., 2002); this, in turn, would threaten the survival and development of the afforested and reforested trees (Cao et al., 2009). Nevertheless, to our knowledge, no study has been carried out yet to investigate the impacts of GGP on regional hydrology, tree survival, and forest growth.

Our study indicates a drastic unprecedented improvement in vegetation or ecological conditions in the region caused by the GGP. Whether these changes can pose long-term overall positive ecological effects requires further study. The remote sensing techniques shown in this study can effectively monitor the land cover changes induced by the GGP. Other techniques such as Lidar (Lefsky et al., 2002) or Radar (Rauste et al., 1994; Breidenbach et al., 2010) may be used to monitor the structural changes of vegetation, the survival, and growth of the new forests, and therefore the effectiveness of the GGP over large areas.

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