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ORIGINAL PAPER

Landscape pattern changes at a catchment scale: a case study in the upper Jinjing river catchment in subtropical central China from 1933 to 2005

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Abstract Land use and cover changes have been reported to have a great association with the alteration of regional ecological functions, and, thus, pose significant changes to the environmental quality. The analysis of landscape pattern changes is regarded as one of the most important prerequisites to quantify such land use and cover changes. Four-year land use maps (1933, 1955, 1990, and 2005) of the upper Jinjing river catchment in Hunan Province in subtropical central China, consisting of an area of 13,500 ha and containing three administrative districts (ADs) (Jinjing, Guanjia, and Tuojia), were used for analyzing the landscape pattern changes. Our results showed that a major landscape pattern has been established since 1933. A moderate changing trend, the decrease of woodland resulting from the increase of paddy field, was also observed. From 1933 to 2005, 1,270 ha of woodland were converted to paddy field, accounting for 13 % of the woodland present in 1933. An analysis of landscape indices demonstrated that the catchment landscape became more heterogeneous from 1933 to 1990, and that the patch fragmenting trend has remained fairly stable since 1990. Compared to the other two ADs, Jinjing showed a contrasting trajectory in the temporal trend of the largest patch index, indicating a distinct urbanization in that AD since 1990. Guanjia showed a different temporal trend in the perimeter-area fractal dimension, suggesting that this district was experiencing disordered development, and, thus, a comprehensive planning should be a concern. The predominant driving forces for the land use changes were found to be the terrain and the governmental policies. Climate change and anthropogenic activities (e.g., rapid population growth and migration) may also be important factors that have impacted the landscape changes of the studied catchment.

Keywords Landscape indices · Land use transition matrix · Driving forces

Introduction

The global landscape has changed dramatically due to human land use consistently interacting with the natural environment for centuries (Forman and Godron 1986). There is international concern regarding the impacts of land use, with particular attention paid to developing countries because of their susceptibility. The people of southern China have been cultivating rice for at least 8,000 years (Fujiwara 1993) and planting tea for more than 3,000 years (Musgrave and Musgrave 2002). These activities have transformed the entire landscape of southern China. The landscape changes are significant because land cover provides many ecosystem services and goods, including the production of food, energy resource and recreation. But recent landscape changes have been both rapid and on a large scale, and threaten to reduce the number and quality of ecosystem services and goods, including soil loss, non-point source pollution, weather changes, and species extinction (Napton et al. 2010). To solve the problems resulting from landscape changes, a quantitative measure of the historic range of variability in landscape structure and composition is necessary to be researched (Bender et al. 2005).

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The spatial patterns and dynamic relationships of landscapes in particular regions over time have been the subject of frequent investigations (Urban et al. 1987; Xie et al. 2006; Falcucci et al. 2007; Fischer and Lindenmayer 2007; Teixeira et al. 2009; Zhou et al. 2011). The methodology of quantitative analysis of landscape pattern structure and its change based on landscape indices has been one of the key issues in landscape ecology studies (Roy 1999; Perry 2002; Dong et al. 2009). There have been a number of studies involving landscape change analysis in China (e.g., Zhang et al. 2000, 2002, 2003; He et al. 2004; Fu et al. 2005; Liu et al. 2005; Shao et al. 2005; Fujihara et al. 2010; Fu et al. 2011; Jiang et al. 2011; Zhao et al. 2011), however, very few have been performed at the catchment scale in the hilly regions of subtropical central China (Lu and Suo 2010). A catchment is a geophysical functional region, which is widely used in hydrology and ecology, and it has also been advocated as an appropriate unit for ecological planning (Steiner et al. 2000). Liu et al. (2003) indicated that quantifying landscape pattern changes by catchment extent is more ecologically meaningful than the extent delimited by rectangular boundaries or administrative units.

The upper Jinjing river catchment is a typical landscape of the hilly red soil region of southern China, 70 km north of Changsha (the capital city of Hunan Province). Several changes in land use and cover have taken place in the catchment during the past 80 years. The history of the study area can be divided into three periods described as follows (Hageback et al. 2005). The first period was prior to the foundation of the People's Republic of China in 1949. We used a 1933 historical landscape map to represent the land use during this period. Only a few people lived in the area due to consecutive years of war. Landlords owned most of the lands, and the peasants had to rent lands from them. Per capita paddy field yields were marginal compared to current yields, and large areas were therefore used as farmlands. During the first period, paddy fields and woodlands were the major components as the landscape matrix took shape. The second period lasted from 1949 to 1999 and included five major historical events: the foundation of the People's Republic of China in 1949, the first and second land reforms, the household responsibility policy, the economic reform and the opening to the outside world policy. The farmers were offered land use rights through the implementation of land reforms and the household responsibility policy. The third period lasted from 1999 to 2005. The Grain to Green program has been applied in the study area since 1999. The farmers began to plant new trees on the farmlands which had previously been transformed from woodlands during the past decade with grain and money as compensation incentives.

With the significant increase in land use and cover changes in the upper Jinjing catchment, especially the rapid expansions of tea field and residential area and the shrink of woodland, certain environmental issues emerged and became severe, such as nitrogen and phosphorous non-point pollution and greenhouse gas emissions (Fu et al. 2012). To thoroughly solve the problems resulting from land use and cover changes, a quantitative analysis of the landscape pattern changes is necessary. The main objectives of the present study were: (1) to analyze the landscape pattern changes of the upper Jinjing river catchment during the period from 1933 to 2005; and (2) to elucidate the predominant driving forces underlying the land use changes in the river catchment during the past 80 years.

Materials and methods

Study area

The upper Jinjing river catchment, located in Jinjing, Changsha, Hunan Province (Fig. 1), is an area of 13,500 ha with a population of 41,618 people. It is one of the headwater sub-catchments located within the Jinjing river catchment system, which is one of the major tributaries of the Xiangjiang river watershed system.

The region has a subtropical monsoon climate with a mean annual air temperature of 17.5 °C and a mean annual precipitation of 1,330 mm. It has four distinct seasons: spring (February–April), summer (May–July), autumn (August–November) and winter (December–January). On average, 70 % of the annual precipitation falls during the warming months of April, May, and June. The altitude is between 56 and 440 m above sea level. The main soil types in the study area are red, purplish, fluvo-aquic, and paddy soils; the dominant soils are red and paddy soils. The natural vegetation includes Masson pine, Chinese fir, oil-tea camellia, and other evergreen trees and shrubs. The cover rate of subtropical evergreen broad-leaf forest is low in the study area. Jinjing town is the only administrative unit in the area and consists of 14 villages. The town is well-known in the region for its booming tea industry in recent decades (Fu et al. 2012).

Data

Four historical land use maps that covered the study area containing three administrative districts (AD) (Jinjing, Guanjia, and Tuojia) and spanned the temporal frames of 1933, 1955, 1990, and 2005 (Fig. 2) were used. The data were created from historical cadastral maps at a scale of 1:10,000 using ArcGIS^{TM} 9.3 software (ESRI, USA). The historical cadastral maps were obtained from the Hunan Provincial Geomatics Information Center (http://www.hnpgc.com). The land use types in the area are classified as woodland, paddy field, tea field, road, residential area,

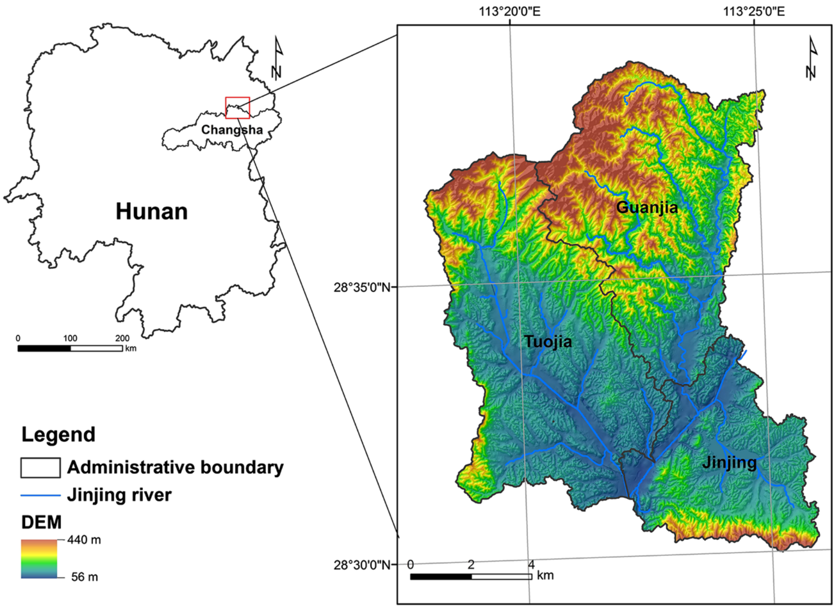


Fig. 1 The geographical location of the upper Jinjing river catchment in Jinjing town, 70 km north of Changsha (the capital city of Hunan Province, P.R. China)

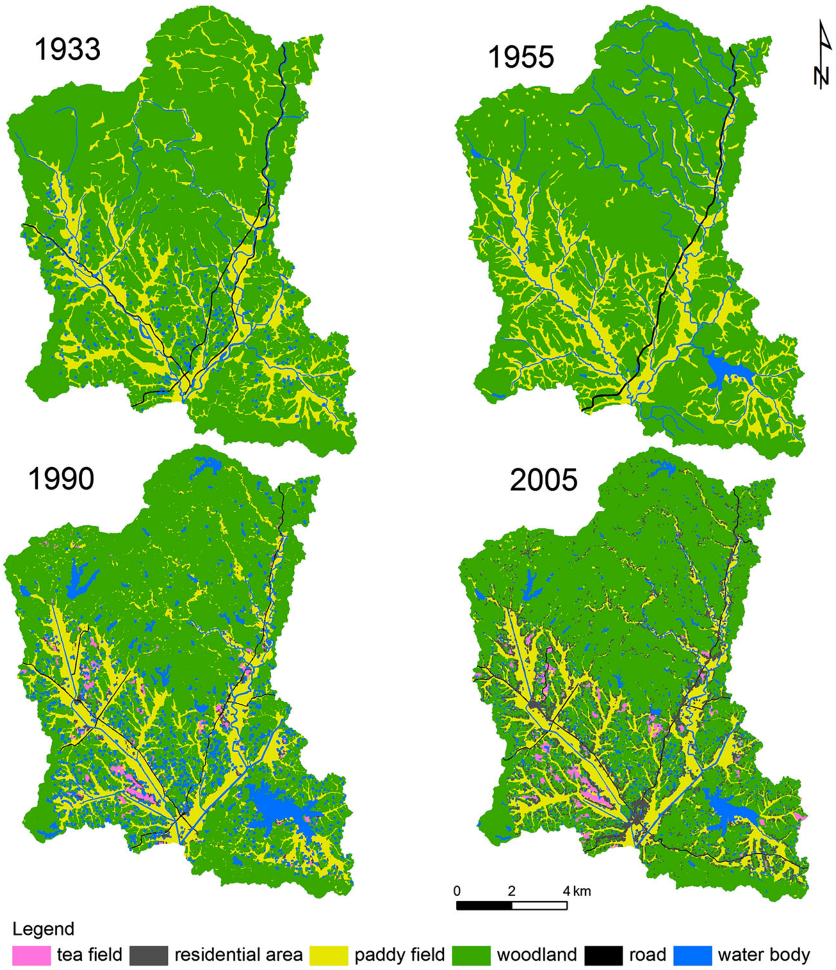


Fig. 2 Historic land use maps of 1933, 1955, 1990, and 2005 of the upper Jinjing river catchment

and water body (e.g., drainage-irrigation channel, river, and reservoir).

A digital elevation model (DEM) was generated from contour data, 4,348 extra elevation control points and a river network using ArcGIS. The meteorological data were obtained from the Changsha weather station from 1955 to 2010, and the population data were collected from the Jinjing local government.

Landscape transition matrix and landscape indices

Landscape area change, change ratio and change direction of various landscape types can be obtained from a landscape transition matrix (Li et al. 2001, 2004; Dong et al. 2009). In the present study, landscape pattern change analysis was performed on a series of two successive time slices: 1933–1955, 1955–1990, and 1990–2005 to reveal the locations of land use changes and to elucidate the "from-to" nature of land use and cover transitions. The change analysis for a specific time period (e.g., 1933–1955) was conducted by overlaying the land use maps of two discrete years, and the subsequent conversion was then calculated and analyzed.

Landscape indices have been found to be effective in studies of scale effects and scale characteristics of landscape patterns (Jelinski and Wu 1996; Wu 2002). Landscape indices for all of the maps were calculated using the raster version of the FRAGSTATS program (McGarigal and Marks 1994). Based on the previously reported investigations (O'Neill et al. 1988; Turner and Gardner 1991) and our prior experimental study on the landscape indices for the four historic land use maps, five relevant landscape indices were chosen to describe the landscape characteristics at the catchment level in this study: number of patches (NP), largest patch index (LPI), landscape shape index (LSI), Shannon's evenness index (SHEI) and perimeter-area fractal dimension (PAFRAC). We also used patch density (PD), LPI, LSI, and PAFRAC to illustrate the landscape pattern at the class level (Table 1). The mathematical expressions of the landscape indices were in accordance with FRAGSTATS (Turner 1989; Turner and Meyer 1991; Gardner and O'Neill 1991; Baker and Cai 1992; McGarigal and Marks 1994; Hessburg et al. 1999; Xie et al. 2006; Zhou et al. 2011; McGarigal et al. 2012). Using ArcGIS, the historical land use vector data were converted to grids at a 5-m spatial resolution, at which the

Table 1 Description of landscape indices

Acronym	Name	Formula	Description	Unit	Range
PD	Patch density	$\mathrm{PD} = \frac{n_i}{A} \times 10{,}000 \times 100$ n_i = number of patches, and A = total landscape area (m^2)	PD expresses the number of patches within the entire reference unit on a per area basis (100 ha), reflecting landscape fragmentation	n/100 ha	$\mathrm{PD} > 0$
LPI	Largest patch index	$\mathrm{LPI} = \frac{\overset{n}{\underset{i=1}{\max}}(a_i)}{A} \times 100$ a_i = area of patch i (m^2), and A = total landscape area (m^2)	The percentage of the landscape comprised by the largest patch; identifying the dominating landscape types	Percentage	$0 < \mathrm{LPI} \leq 100$
LSI	Landscape shape index	$\mathrm{LSI} = \frac{25\sum_{k=1}^{m} e_{ik}}{\sqrt{A}}$ e_{ik} = total length of edge between patch types i and k (m), m = number of patch types in the landscape, and A = total landscape area (m^2)	LSI reflects a more accurate and meaningful way to standardize the shape index	Dimensionless	$\mathrm{LSI} \geq 1$
SHEI	Shannon's evenness index	$\mathrm{SHEI} = \frac{-\sum_{i=1}^{m}(P_i \times \log P_i)}{\log m}$ P_i = proportion of the landscape occupied by patch type i, and m = number of patch types present in the landscape, excluding the landscape border if present	Minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion, divided by the logarithm of the number of patch types; measuring spatial diversity of landscape	Dimensionless	$0 \leq \mathrm{SHEI} \leq 1$
PAFRAC	Perimeter-area fractal dimension	$\mathrm{PAFRAC} = \frac{2}{\frac{n_i\sum_{i=1}^{n}(\log p_i - \log a_i) - \sum_{i=1}^{n} p_i \sum_{i=1}^{n} a_i}{n_i\sum_{i=1}^{n}\log p_i^2 - \left(\sum_{i=1}^{n}\log p_i\right)^2}}$ a_i = area of patch i (m^2), p_i = perimeter of patch i (m), and n_i = number of patches in the landscape of patch type i	PAFRAC describes the power relationship between patch area and perimeter, reflecting landscape heterogeneity	Dimensionless	$1 \leq \mathrm{PAFRAC} \leq 2$

smallest landscape patches (such as residential area and small water bodies) can be clearly identified.

In culture landscapes, anthropogenic processes are of central importance in the analyses of spatio-temporal landscape configurations and composition changes (Houghton 1994; Reid et al. 2000). Ecological studies of landscapes have to be closely linked to the hierarchical structure of the administrative units (Bender et al. 2005). We adopted a landscape transect research methodology to explore the deep-rooted and underlying landscape information (Luck and Wu 2002; Ernoult et al. 2006; Xie et al. 2006). The upper Jinjing river catchment included three ADs (Jinjing, Guanjia, and Tuojia). Their respective characteristic landscape compositions and patterns resulted from different natural environmental and economic situations. Some land use change information may be covered on the scale of the entire landscape, and; hence, it is worth dividing the study area into three parts (Jinjing, Guanjia, and Tuojia) according to the original administrative boundaries to analyze the landscape changes (Fig. 1). We computed two landscape indices (LPI and PAFRAC) to quantify and analyze the temporal changes of the landscape compositions and the landscape configurations.

Driving force analysis

The driving forces of landscape pattern changes can originate from topography, anthropogenic activity, governmental policy and climate change. An advanced understanding of the roles of these driving forces and how they interact with each other is crucial for us to evaluate what specific forces are predominant in determining the landscape pattern changes (Napton et al. 2010).

Generally, driving forces can be grouped into three categories (Turner et al. 1995): biophysical factors, socio-economic drivers and proximate causes. Although biophysical factors, such as elevation and soil type, mostly do not directly drive land use change, they can influence land use allocation decisions and lead to land use and cover changes (Verburg et al. 2004). We chose five representative driving forces (elevation, slope, soil type, population, and climate change) to explore the relationships between driving forces and land use changes.

In this study, we did not have a comprehensive data set covering population change and climate change from 1933 to 2005 for quantifying their relationships with landscape pattern changes. As a compromise, we only applied a descriptive approach to explore those relationships. Two-year population data for 1990 and 2005 collected from the Jinjing local government were attributed to the village map and used to generate the population change map. We overlaid the population change map and the land use change map to analyze the relationship between the spatio-temporal variation of population and land use. The Pearson's correlation analysis was used to quantify the above relationship. The relationship between climate change (derived from the recorded climate data for 1955–2008) and land use change was descriptively analyzed.

Because land use type and soil type are category variables, parametric statistic methods (e.g., the Pearson's correlation and multivariate regressions) could not be used. Thus, the classification and regression tree (CART) methods (such as random forest and multivariate regression trees) were applied to analyze the biophysical drivers (e.g., elevation, slope, and soil type) for land use changes. In this study, the R statistical software (http://www.r-project.org) and two of its CART packages (randomForest and mvpart) were employed for data analysis. Random forest is an ensemble classifier that consists of many decision trees and outputs the class that is the classes' output by individual trees. Each of the trees is built from a further random subset of the total predictors who maximize the classification criteria at each node (Breiman 2001). The R package of randomForest gives estimates of which variables are important in the classification, but its classifying results are difficult for humans to interpret in comparison with a multivariate regression tree. The R package of mvpart extends the CART approach to multivariate response data. It makes no assumptions about the form of the relationships between land use change and their driving forces and models the relationships and forms clusters by repeated splitting of the data, with each split chosen to minimize the dissimilarity within clusters (Hamann et al. 2011). A decision tree plotted by mvpart is a forecasting tree-like diagram resulting from recursive partitioning of the response data, with indication of the influence of the explanatory variables at each split. Further detailed descriptions of randomForest and mvpart were referred to http://www.r-project.org. In this study, randomForest was used to evaluate the importance of driving factors, and mvpart was employed to develop and plot the regression trees, describing the relationships between land use changes and driving forces.

Results

Landscape transition matrix

From 1933 to 2005, the same landscape pattern has emerged since 1933, even though a major trend was observed, which consisted in presenting a decrease in the woodland area resulting from an increase in arable land and tea fields (Fig. 2). There were conspicuous differences in landscape conversion during the three periods. Roads and rivers seldom changed during the period of 1933–2005.

The transition matrix of landscape changes from 1933 to 1955 (Table 2) indicated that the three most prominent types of conversions are those from paddy fields to reservoirs, from woodland to paddy fields and from paddy fields to woodland (68, 1,272, and 1,334 ha, respectively). The conversions from woodland to residential areas and from paddy fields to residential areas were also notable (90 and 40 ha, respectively). The conversion from paddy fields to reservoirs is the most obvious.

For the landscape transition matrix from 1955 to 1990 (Table 3), the two dominant conversions are those from woodland to tea fields and from woodland to paddy fields (366 and 1,223 ha, respectively). The emergence of tea fields during this period made the conversion more complicated. Twenty percent of the tea fields were transformed from paddy fields and the rest were converted from woodland. The conversions from woodland to residential areas and from river to paddy fields are also notable (479 and 144 ha, respectively).

The landscape conversion during the period of 1990–2005 was generally less remarkable than those during the two earlier periods (Table 4). The most conspicuous conversions from 1990 to 2005 were those from tea fields to woodland (164 ha), from tea fields to paddy fields (58 ha) and from woodland to paddy fields (321 ha).

Landscape indices

At the class level

The range of values in landscape indices at the class level from 1933 to 2005 are shown in Table 5.

Table 2 1933–1955 land use transition matrix (ha)

1933	1955					
	Residential area	Paddy field	Woodland	Road	Reservoir	River
Residential area	4.47	21.85	32.09	0.40	0.61	0.62
Paddy field	39.52	1,794.40	1,334.63	14.85	68.08	109.23
Woodland	90.07	1,272.78	8,272.85	35.14	22.70	95.34
Road	0.79	30.31	17.50	7.32	0.40	2.94
Reservoir	0.82	26.22	31.04	0.73	1.92	0.23
River	1.21	57.26	35.56	0.74	3.91	13.77

Table 3 1955–1990 land use transition matrix (ha)

1955	1990						
	Tea field	Residential area	Paddy field	Woodland	Road	Reservoir	River
Residential area	4.02	48.92	26.51	53.81	0.17	3.21	0.23
Paddy field	34.95	225.52	2,130.97	593.65	10.99	144.79	61.94
Woodland	366.01	478.50	1,223.26	7,420.09	3.14	223.62	9.04
Road	2.40	14.54	19.16	16.54	4.43	1.83	0.31
Reservoir	0.10	0.20	4.77	2.51	0.04	90.02	0.00
River	0.23	7.70	143.66	31.83	1.52	10.47	26.72

Table 4 1990–2005 land use transition matrix (ha)

1990	2005						
	Tea field	Residential area	Paddy field	Woodland	Road	Reservoir	River
Tea field	176.72	6.48	57.67	164.04	1.62	1.15	0.02
Residential area	13.10	215.20	170.87	367.53	4.10	4.05	0.53
Paddy field	29.41	32.08	2,871.28	559.69	14.00	31.64	10.22
Woodland	105.11	51.91	320.74	7,617.54	4.86	16.80	1.47
Road	0.03	0.72	7.34	1.31	10.83	0.00	0.05
Reservoir	3.71	4.20	116.20	85.86	0.22	263.44	0.31
River	0.25	0.20	37.91	2.19	1.00	0.28	56.42

Residential areas were the most widely spatially distributed landscape type (Table 5). From 1933 to 2005, PD increased at a varying rate, i.e., PD ranged from 5.15 to 10.51 for 1933–1955, from 10.51 to 17.15 for 1955–1990, and from 17.45 to 39.54 for 1990–2005, suggesting that the population of the region has increased irregularly since 1933.

Paddy fields and woodlands accounted for approximately 90 % of the total area during 1933–2005 and were the most highly varied landscape types. The PD values of paddy fields increased from 1.06 to 9.37 during 1933–1990 and then decreased to 6.68 during 1990–2005. This trend suggests that the paddy fields had been fragmented due to disordered development planning until 1990 and were then homogenized under unified planning after 1990. The LPI values of paddy fields were shown the highest in 1933, decreased sharply from 5.33 to 1.95 during 1933–1955, and then increased gradually from 1.95 to 4.35 during 1955–2005. The temporal changes of LPI illustrated that paddy fields were more fragmented in 1955. The LSI and PAFRAC values of paddy fields (respectively, in each case) decreased from 45.50 and 1.17 in 1933 to 39.12 and 1.13 in 1955, increased from 39.12 and 1.13 in 1955 to 78.49 and 1.16 in 1990, and decreased from 78.49 and 1.16 in 1990 to 74.98 and 1.15 in 2005. These constant fluctuations indicated that the variations of paddy field are based on large alterations in both quantity and shape.

The landscape indices of woodlands had a variation tendency different from that of paddy fields. The PD values of woodland areas increase consistently from 0.56 to 3.04 during 1933–2005, indicating that the woodlands had fragmented and were easily converted to other landscape types. The LPI values of paddy fields and woodlands were inversely correlated with each other in 1955.

Table 5 Landscape index analysis at the class level

Land use	Year	PD	LPI	LSI	PAFRAC
Residential area	1933	5.15	0.005	29.88	1.049
	1955	10.51	0.006	44.53	1.055
	1990	17.45	0.105	66.69	1.088
	2005	39.54	0.061	96.34	1.102
Paddy field	1933	1.06	5.326	45.50	1.170
	1955	1.50	1.948	39.12	1.129
	1990	9.37	3.190	78.49	1.160
	2005	6.68	4.354	74.98	1.146
Woodland	1933	0.56	13.234	26.03	1.136
	1955	0.57	43.376	26.20	1.148
	1990	1.50	38.488	56.83	1.154
	2005	3.04	38.786	56.18	1.131
Reservoir	1933	2.42	0.019	21.04	1.050
	1955	0.23	0.589	5.35	1.076
	1990	7.06	1.392	36.44	1.075
	2005	7.69	0.808	33.45	1.070

PD (*n*/100 ha) patch density, *LPI* (%) largest patch index, *LSI* landscape shape index, *PAFRAC* perimeter-area fractal dimension

Reservoirs played an important role during the study period because of their close relationship with paddy fields. One of the most conspicuous changes for reservoirs is that the PD value dramatically decreased by more than two units (from 2.42 to 0.23) from 1933 to 1955 and then sharply increased from 1955 to 1990.

At the administrative district level

The landscape changes in the three ADs in 1933, 1955, 1990, and 2005 were analyzed. Tuojia and Guanjia LPIs showed the same variation trend as the entire landscape LPI, but the Jinjing LPI showed a distinct variation trend (Fig. 3). This finding indicated that a distinct urbanization process has occurred since 1990. The urbanization was mainly manifested primarily by population migration and tea field combination. The temporal trends for PAFRAC were similar for Tuojia, Jinjing and the entire landscape but different for the Guanjia district (Fig. 4). These findings suggest that the three districts showed distinctive landscape

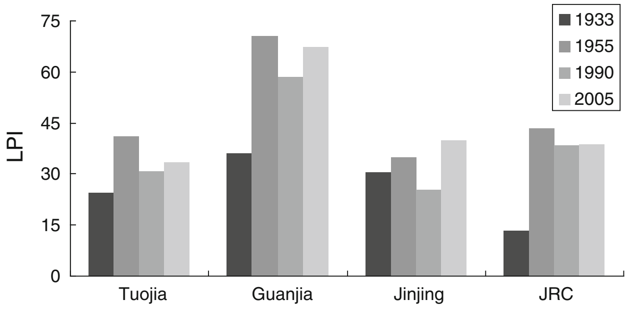


Fig. 3 Comparison of the largest patch indies (LPI) between the upper Jinjing river catchment (JRC) and the three administrative districts of Tuojia, Guanjia, and Jinjing

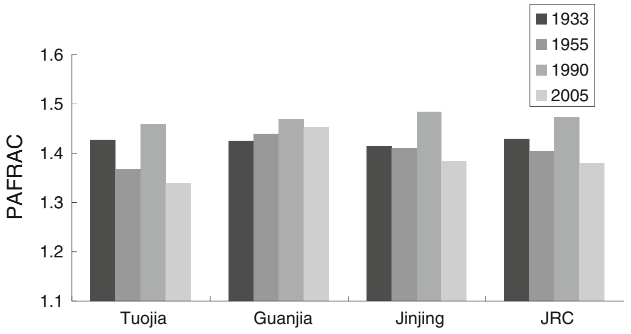


Fig. 4 Comparison of the perimeter-area fractal dimensions (PAFRAC) between the upper Jinjing river catchment (JRC) and the three districts of Tuojia, Guanjia and Jinjing

patterns in regards to the heterogeneity, and that Guanjia was more heterogeneous than the other two districts. Thus, Guanjia may have experienced a disordered development, which is a concern in comprehensive planning.

At the catchment level

From 1933 to 2005, the NP values increased from 1,273 to 7,786 with years, showing a trend of increasing fragmentation in the upper Jinjing river catchment (Table 6). LPI was highest in 1955, indicating that the landscape was more homogeneous in that year. The LSI and SHEI values reflect the heterogeneous patterns of the landscapes. LSI and SHEI were higher during 1990–2005 than during 1933–1955, indicating that the landscape heterogeneity and evenness consistently increased over time. Both of these indices were slightly lower in 2005 than in 1990, indicating a trend toward landscape homogeneity and uniformity since 1990. The PAFRAC values fluctuated during 1933–2005, indicating the inconsistent and complex conversions of landscapes in the catchment.

Driving factors of landscape changes

Anthropogenic activities

The population of the upper Jinjing river catchment increased from 4,308 to 41,618 during 1933–2005. The area of paddy fields also expanded but at a much lower rate, and was not significantly related to the rate of population increase. Some apparent landscape transitions from paddy fields to reservoirs during 1933–2005 and from woodlands to tea fields during 1955–1990 were due mainly to the related national land use policies (Hageback et al. 2005). The population growth in the catchment resulted directly in the sharp expansion of residential areas.

From 1990 to 2005, there was a clear population movement from scattered and remote villages to Jinjing town (Fig. 5), resulting from the contemporary regional urbanization process. However, the relationship between the land use conversions and the population movement was not clearly demonstrated in Fig. 6, in which almost every breakpoint of population change had a landscape conversion peak. The Pearson's correlations between the population change and land use conversions were not significant, with correlation coefficients ranging from -0.51 to 0.31 ($p > 0.05$).

Table 6 Landscape index analysis at the catchment level

Year	NP	LPI	LSI	SHEI	PAFRAC
1933	1,273	13.23	28.38	0.36	1.43
1955	1,741	43.38	28.39	0.42	1.40
1990	5,517	38.49	59.22	0.56	1.47
2005	7,786	38.79	56.89	0.48	1.38

NP number of patches, *LPI* (%) largest patch index, *LSI* landscape shape index, *SHEI* Shannon's evenness index, *PAFRAC* perimeter-area fractal dimension

Climate change

The upper Jinjing river catchment has a subtropical monsoon climate, and the temperature and precipitation are favorable for rice plantations. The climate data recorded at the Jinjing weather station from 1955 to 2008 (Fig. 7) showed a decreasing trend in annual precipitation since 1995 and a mean annual precipitation of 1,330 mm. The mean annual air temperature is 17.5 °C, and the average annual maximum air temperature and minimum air temperature values both increased since 1990. The decrease in precipitation and the increase in temperature were expected to affect the area of reservoirs in the catchment (Fig. 8). From 1990 to 2005, the reservoir area decreased by approximately 157 ha. This decrease was concentrated mainly along the several large reservoirs (Fig. 8). The reservoirs provide the major source of irrigation water in the region. Some paddy fields were abandoned because of

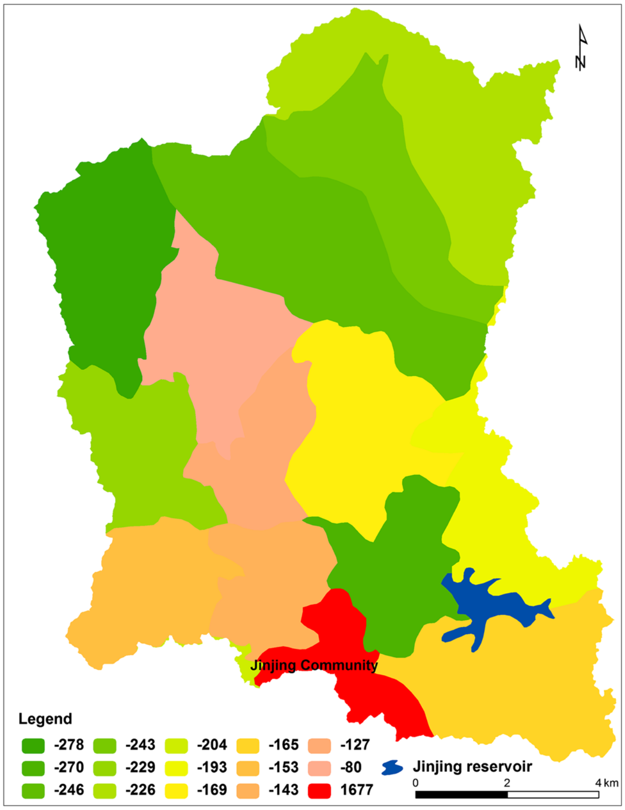


Fig. 5 Population spatial change during 1990–2005 in the upper Jinjing river catchment

Fig. 6 Relationship between conversions of land use type and spatio-temporal population changes in the upper Jinjing river catchment during 1990–2005

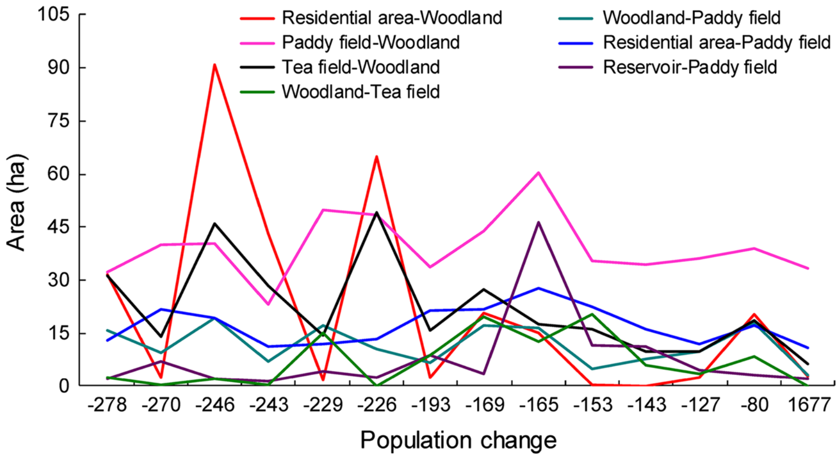


Fig. 7 Dynamics of annual precipitation and annual average temperature at the Changsha weather station from 1955 to 2008 and associated temporal changes of paddy field and woodland in the upper Jinjing river catchment from 1990 to 2005

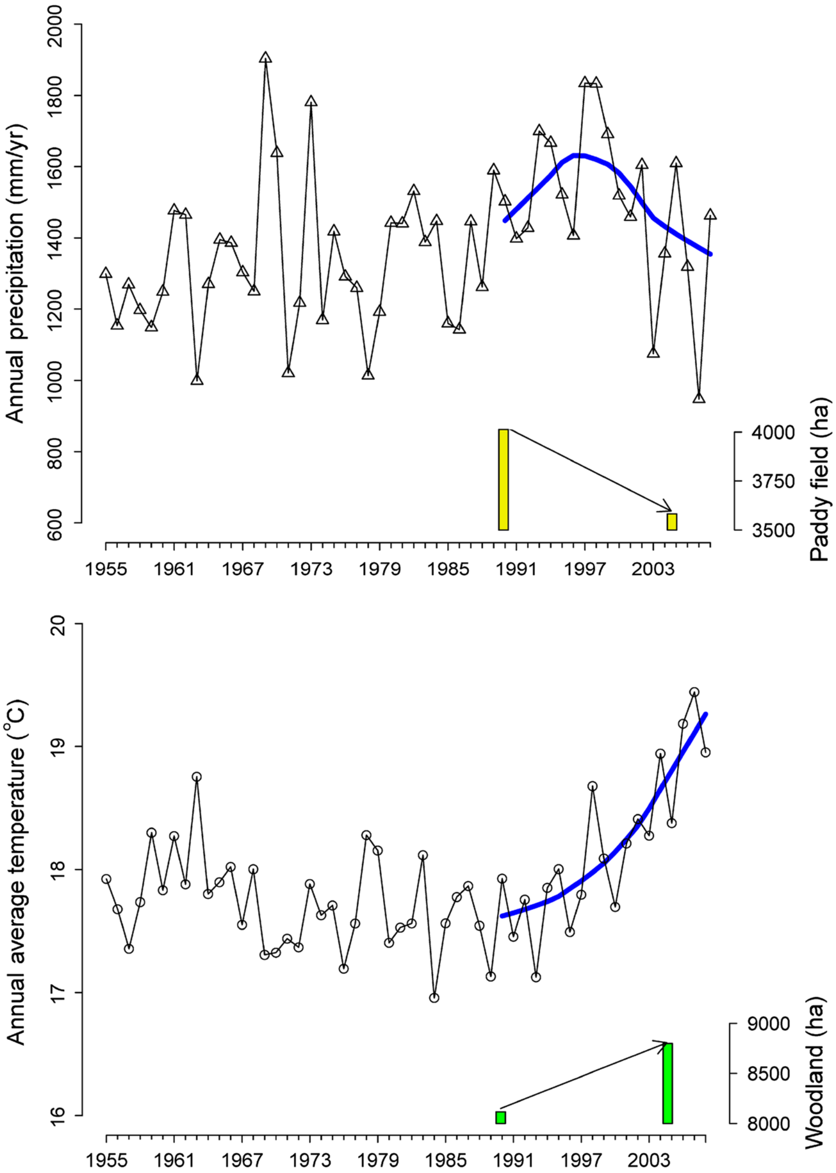
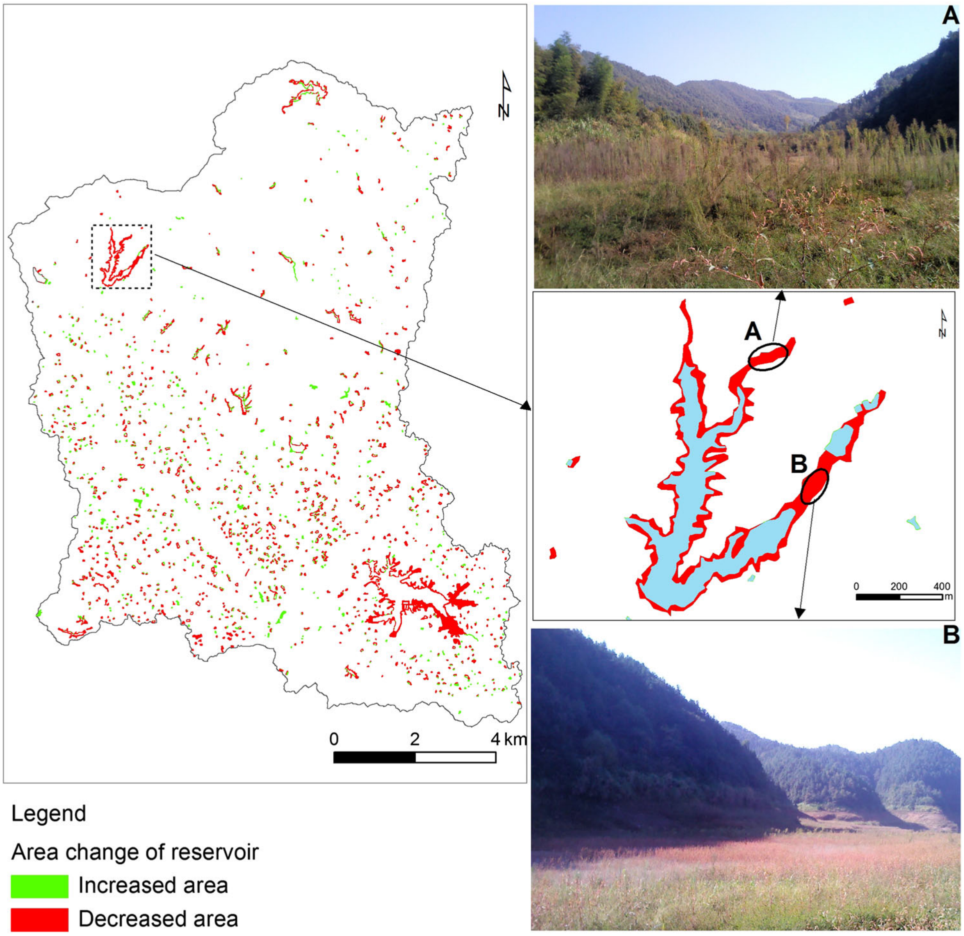


Fig. 8 Spatial change of reservoir areas during 1990–2005



the reduction of reservoir area. For instance, paddy fields were decreased by 430.9 ha from 1990 to 2005, while woodlands were increased by 679.7 ha, not only from the conversion of the abandoned paddy fields, but also from long-term dried-out reservoirs and other land use types.

Biophysical driving forces

As seen in Fig. 9, the importance of four driving forces of elevation, slope, and soil type varied during the period of 1933–2005. However, the elevation always kept a predominant importance value, indicating that elevation is a determining factor in forming the landscape patterns of the region.

In the CART model obtained (Fig. 10), the most important factor was elevation (similar to the result of the random forest analysis), which split the first layer by the thresholds of approximately 95 m and the second layer by the thresholds of approximately 75 m from 1933 to 2005. For instance, in the areas with the elevations equal to or greater than the first-layer thresholds, the dominant land use type was shown as woodland, while in the areas with the elevations less than the second level thresholds, the major land use type was the paddy field. On the third layer, the splits of trees were determined by soil type, except for 1990 still by the elevation. The determining factor for the fourth layer was slope, except for 1990 when soil type started to take control of splitting trees for paddy field and woodland. In general, the tree structures of CART models obtained for 1933, 1955, and 2005 were close, frameworked by three driving forces in order of elevation, soil type, and slope.

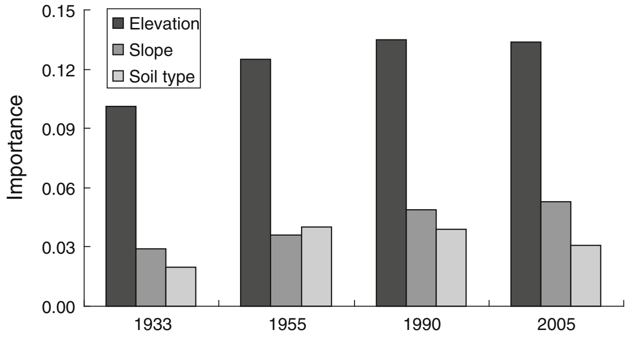


Fig. 9 The importance of the three biophysical driving forces (elevation, slope, and soil type) to the land use classification from 1933 to 2005 by using the random forest analysis

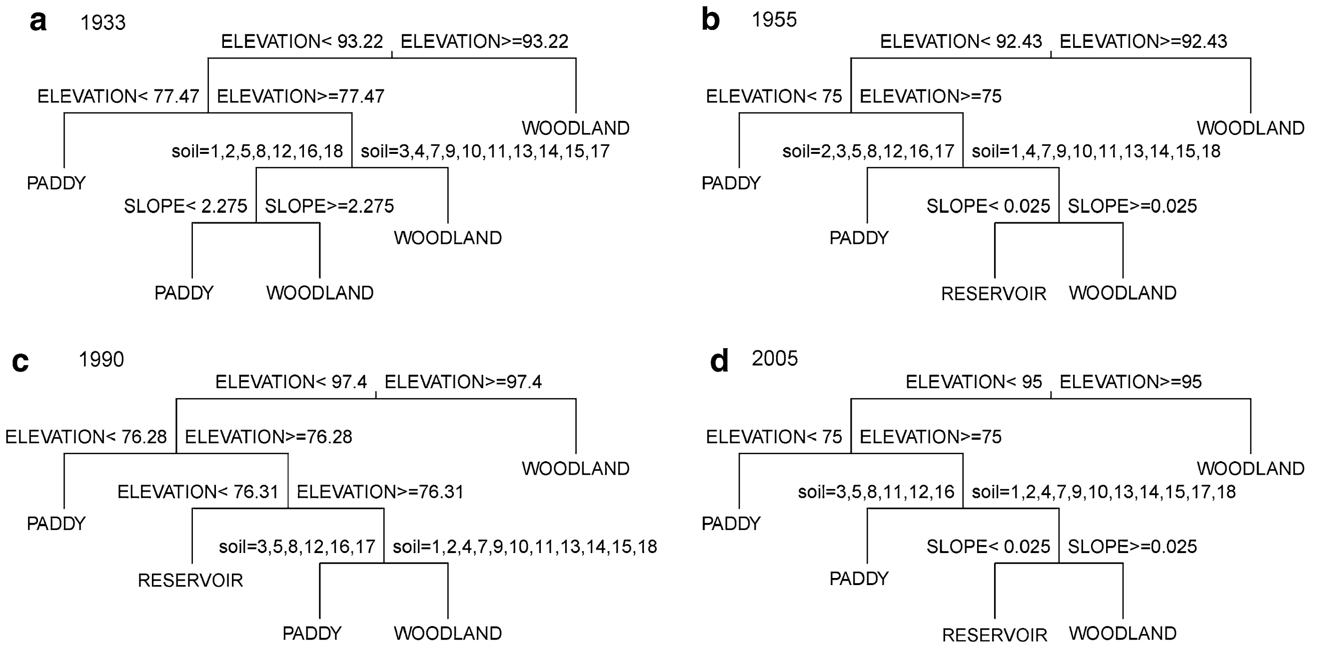


Fig. 10 The classification and regression tree (CART) models for describing the relationship between the three biophysical driving forces and the land use classification for **a** 1933, **b** 1955, **c** 1990, and **d** 2005. Note that the soil numbers refer to soil types

Discussion

Cultural landscapes (e.g., the upper Jinjing river catchment) provide a unique opportunity for us to understand ecosystem dynamics within an ecological setting that has experienced changes driven by institutional alteration, commercial development, climate, terrain, etc. (Hamre et al. 2007).

The upper Jinjing river catchment underwent dramatic changes from 1933 to 2005. It is one of the best available reference areas in subtropical China for studying the ecological effects of past events. We have quantitatively measured the landscape patterns during the past 80 years and described how the spatial structures have been altered in relation to major institutional policies (i.e., the Grain to Green Program) and the natural environment.

Essentially the same landscape pattern has been observed in the upper Jinjing river catchment since 1933, although there was a major trend toward a decrease in woodlands resulting from an increase in arable lands. Woodlands and paddy fields consistently accounted for more than 87 % of the total area during 1933–2005. The large conversions of woodlands to paddy fields during 1933–1955 and 1955–1990 were expectedly due to the national land use policies and the rapid population growth over those times. Reservoirs and tea fields were two other land use types that also influenced the landscape patterns. From 1933 to 1955, paddy fields and woodlands were transformed into reservoirs as a result of the governmental reservoir construction policy. Around Jinjing town, many paddy fields were converted to reservoirs to mitigate consequences of frequent floods and droughts. From 1990 to 2005, woodlands and paddy fields were transformed to tea fields because of the Jinjing government's economic policy. Jinjing has had a history of tea production history because its natural environment (i.e., well-drained and acidic soils) is favorable for tea plantation (Musgrave and Musgrave 2002). Before 1990, householders were the dominant units for tea plantations. However, during the development of non-agricultural industries, the tea fields of many individual farmers were taken over by large tea enterprises (e.g., the Xiangfen Tea Corporation and the Jinjing Tea Corporation). The tea industry is now a major local industry, in which approximately 10 % of the local populations is employed (see http://jjz.csx.cn/cjpt/tjc); this is one of the reasons why some paddy fields were abandoned or transformed to woodlands.

The landscape indices in the upper Jinjing river catchment at both the catchment and class levels varied greatly during the period of 1933–2005. The LPI during 1933–1955 was higher than during other periods at the catchment level, presumably as a result of the governmental reservoir construction policy. The woodland area was gradually reduced during the past 80 years. A possible reason for this phenomenon was the expansion of paddy fields, tea fields and residential areas that resulted from the explosive population growth. This phenomenon is different from the global deforestation that results mainly from agricultural expansion (Vogelmann 1995; Geist and Lambin 2002; Zipperer 2002; Radeloff et al. 2005; Teixeira et al. 2009). A trend of conversion from paddy fields to woodlands has gradually emerged since 1990, consistent with the general worldwide pattern of forest re-vegetation from abandoned agricultural lands (Whitney 1994; Chapman and Chapman 1999; Ramankutty and Foley 1999; Dupouey et al. 2002; Crk et al. 2009). This phenomenon is not surprising in view of the implementation of the Grain to Green program; the transition rate of reforestation in our study area was faster than that of the forest re-vegetation from abandoned agricultural lands.

The three districts (Jinjing, Tuojia, and Guanjia) differed in their temporal trends of LPI and PAFRAC. Compared with the other ADs, the Jinjing district differed in the temporal trend of LPI, indicating a distinct urbanization there since 1990. The Guanjia district showed a distinct temporal trend in regard to PAFRAC by a couple of reasons. One possible reason for this difference concerned the natural environment: Guanjia contained more than 50 % of the woodland areas of the upper Jinjing river catchment and had paddy fields embedded in the hills (Fig. 2). This distribution of embedded paddy fields increased the PAFRAC value. The second possible reason was associated with the differences in economic structure among the three districts. Guanjia had no individual enterprises, and thus the rice plantation was the major source of economic income; whilst Tuojia and Jinjing had many local governmental and individual enterprises (e.g., the Xiangfen Tea Corporation and the Jinjing Tea Corporation), which may have induced people to move out of the rice production sector. Some remote paddy fields and unsuitable arable lands in Tuojia and Jinjing were therefore abandoned and eventually became woodlands.

Landscape changes are related to some extent with changes in population size, e.g., the area of paddy fields increases with the population size (Fischer and Lindenmayer 2007). Few studies have investigated the relationship between changes in the population spatial distribution and landscape patterns in the small-scale river catchments. Such research focusing on the impact of human populations on landscape pattern changes will be very useful in identifying the major driving forces of the landscape changes. However, in this study, the landscape patterns did not show significant correlations with the spatial distribution of the population, but was correlated with the elevation of the natural environment. There are two possible reasons for this apparent discrepancy. Firstly, in the hilly regions of southern China, it is difficult for people to break through existing natural obstacles (i.e., hills), and this difficulty may restrict interpersonal exchanges and the creation of wealth. Secondly, the human driving force has a weak spatial variability across small-scale river catchments, and barely reflects the landscape pattern changes at the spatial scale.

It is indisputable that climate change impacts landscape change in China (Smit and Cai 1996; National Climate Center 2000), but there are many uncertainties regarding the mechanism for this impact (Reilly and Schimmelpfennig 1999; Hageback et al. 2005). We observed a relationship between climate change and the landscape change in the upper Jinjing river catchment. For example, in the smaller sub-catchments, most of the paddy fields at the higher elevations were abandoned in recent decades due to the lack of sufficient rainfall during the rice growing seasons. However, such a relationship was difficult to quantify for the following reasons. Firstly, some reservoirs were built around 1955 to mitigate certain meteorological emergencies. Secondly, when the weather was not suitable for the rice cultivation, many householders chose to move out to seek other jobs; whereas most of them returned to rice production again after a few years when the climate conditions improved. Finally, urbanization, technology improvement and the new development of tea enterprises may have confounded the impact of climate change on the landscape change.

This study produced a spatio-temporal quantitative estimate of the historical variation in landscape patterns and explored the dominant driving forces leading to landscape pattern changes experienced by the upper Jinjing river catchment. Unfortunately, we were unable to intensively analyze the landscape pattern changes due to the scarcity of historical landscape information (e.g., socio-economic data, historical maps and climate data). Such information is very important for us to understand the present status of the landscape, to monitor its progress to date, and to manage it properly in the future (Hamre et al. 2007). The more landscape information we collect, the more able we are to accurately analyze landscape patterns.

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