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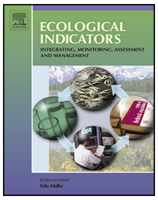

Peri-urban vegetated landscape pattern changes in relation to socioeconomic development

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Peri-urban vegetation, which delivers a diversity of fundamental services, sustains increasing pressures from human activities. Characterizing the socioeconomic drivers of vegetated landscape pattern changes can inform ecological management. Vegetated landscape pattern changes, (including paddy, dryland, woodland, forest, and perennial plantations) in Tiaoxi watershed (China) between 1985 and 2009, were characterized using a set of landscape metrics. Their relationships with socioeconomic development were quantified by multivariable regression. Results showed that Tiaoxi watershed experienced rapid socioeconomic development based on a set of indicators (demography, economy, and social activities). Vegetated landscapes were less abundant and connected, and became more irregular, fragmented, and diverse at landscape level. At class level, increasing fragmentation and isolation were identified for all vegetated landscape types. Paddy, dryland, and forest decreased in area and aggregation, while woodland and perennial plantations presented opposite trends. Socioeconomic drivers of vegetated landscapes pattern changes differed with metrics and with vegetated landscape types. Generally, population growth, road construction, income increase, and tertiary industry development were the major drivers. The identified socioeconomic drivers differed from those for urban areas in previous related report. The inconsistence could be attributed to the different socioeconomic conditions and their interactions with land use practice between urban and peri-urban areas. This study contributed to the identification of key socioeconomic indicators influencing vegetated landscape pattern changes in peri-urban regions.

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1. Introduction

Urbanization has been the most powerful driver of world development in recent decades. Particular emphasis was put on metropolitan cores, since these places experienced continuously dramatic growth. Nevertheless, spatial patterns of urbanization are changing. Urban expansion, concentrates in former metropolitan peripheries, progressively emerges into rural areas and small towns (Aguilar and Ward, 2003). The dispersed urban expansion gives birth to a wide urban–rural interaction zone with increasingly diffuse limits between rural and urban characters (Aguilar, 2008). The transition zone, where rural activities are juxtaposed with urban activities, is labeled as "peri-urban" in literature (Douglas, 2006). Since peri-urban regions present unique characteristics of socioeconomics and ecology, the rapid urban land growth would influence ecosystems' structure and functions (Huang et al., 2009). Ecological consequences of peri-urbanization cannot be ignored (Douglas, 2006), because peri-urbanization would possibly pose greater impacts than the land use that it replaces (Kearney and Macleod, 2006). However, both urban and rural administrations often ignore the ecological changes associated with socioeconomic development in peri-urban areas (Huang et al., 2009).

Peri-urban regions are always rich in vegetation resources, including all cultivated and spontaneous vegetated-cover types, such as woodland, cropland, grassland, and forest. Peri-urban vegetation delivers a diversity of ecological and social services, varying from climate regulation, soil erosion control, and biodiversity maintenance to water quality amelioration, air pollutants absorption, and recreational opportunity supply (Douglas, 2006; Pert et al., 2012; Wagrowski and Hites, 1997). Being sensitive to human activities, peri-urban vegetation has been sustaining increasing pressures (Bajocco et al., 2012; Delm and Gulinck, 2011; Salvati and Zitti, 2012; Tang et al., 2012). Characterizing the socioeconomic

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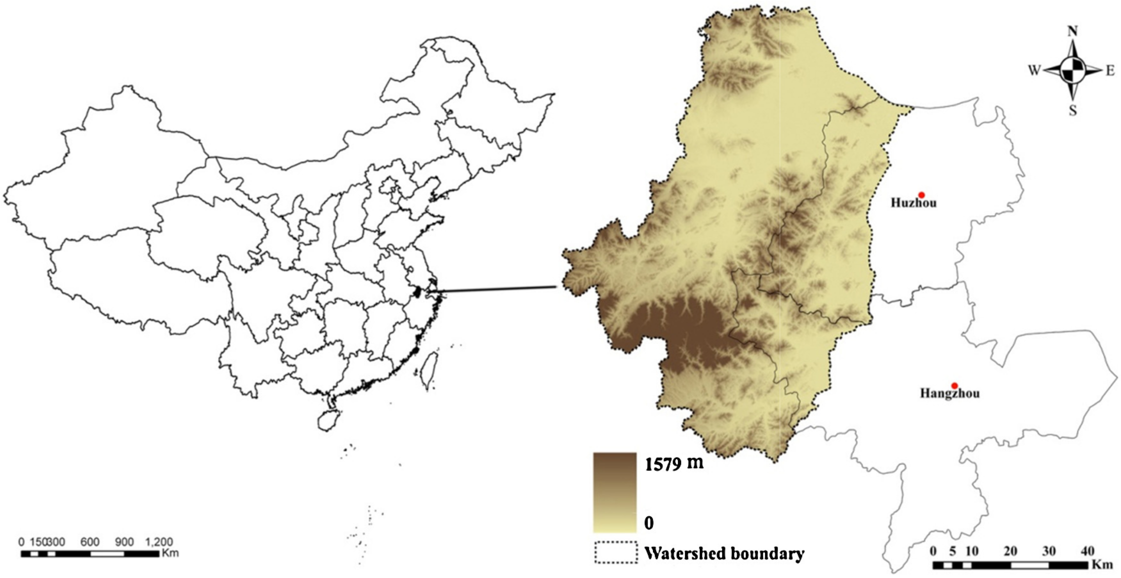

Fig. 1. Location of Tiaoxi watershed within the urban–rural interaction zone of Hangzhou City and Huzhou City, eastern coastal China.

drivers of vegetation dynamic changes should therefore provide critical references for resource conservation and ecological management in peri-urban regions.

Inventory of peri-urban vegetation is on the rise, with the help of remote sensing. Majority of previous studies focused on the spatiotemporal distribution of vegetation cover, areal changes, and species composition (Delm and Gulinck, 2011; Miller, 2012; Tang et al., 2012). Few efforts have been spared on multi-temporal monitoring of structures and functions of vegetated ecosystems, given the high costs of field survey and scarcity of long-term observation data. Enough evidence demonstrates that landscape patterns significantly influence a variety of ecological processes and functions (Leitão and Ahern, 2002; Turner et al., 2007; Weng, 2007), and can be used to indicate the quantitative and qualitative changes of natural resources in an indirect way (Weng, 2007; Su et al., 2012). Compared to field trips, landscape ecological approach can offer overall perceptions of landscape characteristics and can be easily used for management implications (Fernandes et al., 2011; Mairota et al., 2013; Sowińska-Świerkosz and Soszyński, 2014). However, rather few studies have applied landscape ecological approach to investigate peri-urban vegetation dynamics. In addition, the socioeconomic factors governing peri-urban vegetated landscape pattern changes remain poorly understood.

Considering the above mentioned shortcomings, this paper intends to characterize the changes of peri-urban vegetated landscape patterns under rapid socioeconomic development. Data were collected for the Tiaoxi watershed, a typical peri-urban region in the Chinese eastern coast. Our objectives are to: (1) analyze vegetated landscape pattern changes in Tiaoxi watershed between 1985 and 2009, (2) compare the landscape characteristics among different vegetated landscape types, and (3) quantify the relationships between vegetated landscape pattern changes and socioeconomic development.

2. Methodology and data

2.1. Study area

The Tiaoxi watershed lies within the urban–rural interaction zone of Hangzhou City and Huzhou City, two of the most urbanizing megacities in the Chinese eastern coast (Fig. 1). Covering about 6000 km^2, it extends from 119°14′E to 120°13′E, and from 30°07′N to 31°11′N. With a subtropical monsoon climate, annual mean temperature reaches 17.5 °C and rainfall amounts to 1100 mm. Tiaoxi watershed is superior in ecological quality with high vegetation coverage. Since the 1980s, Hangzhou City and Huzhou City have been experiencing rapid urbanization, which stimulated the socioeconomic development in their surrounding peri-urban areas. Such rapid socioeconomic development spurred intensive built-up land expansion in Tiaoxi watershed (Su et al., 2011). Vegetated area has been gradually depleted and vegetated landscape pattern would be transformed. This watershed not only exemplifies rapid socioeconomic development mirrored in many peri-urban areas worldwide, but also represents the ecological degradation of vegetation resources faced by developing countries under urbanization. The case of Tiaoxi watershed can therefore be typically relied on to analyze peri-urban vegetated landscape pattern changes in relation to socioeconomic development.

2.2. Images processing

The primary land use data was from Su et al. (2014a). Remotely sensed data source included Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper (ETM+), and China–Brazil Earth Resources Satellite (CBERS). TM images were collected for years of 1985, 1994, 2005, and 2009; ETM+ images were collected for years of 1999, 2000, 2001, 2002, and 2003; CBERS images were collected for years of 2004, 2006, and 2007. Pre-processing details were described in Su et al. (2014a). Considering the dominant vegetated landscape elements and image resolution, five vegetated landscape types (paddy, dryland, sparse woodland, dense forest, perennial plantations) were visually interpreted from remotely sensed images. We first interpreted the 2009 vegetated landscape type map, and assessed its accuracy in reference to 80 points collected in field trips. The overall accuracy reached 91.7%, and Kappa index was 90.1. Then, it was used as reference for the other years. The final output is a vector dataset. We only displayed four years of vegetated landscape type maps (Fig. 2), to give the readers the possibility to get an overview.

2.3. Selection of landscape metrics

Metric analysis provides an effective way for quantitative description of landscape patterns (Leitão and Ahern, 2002; Lang

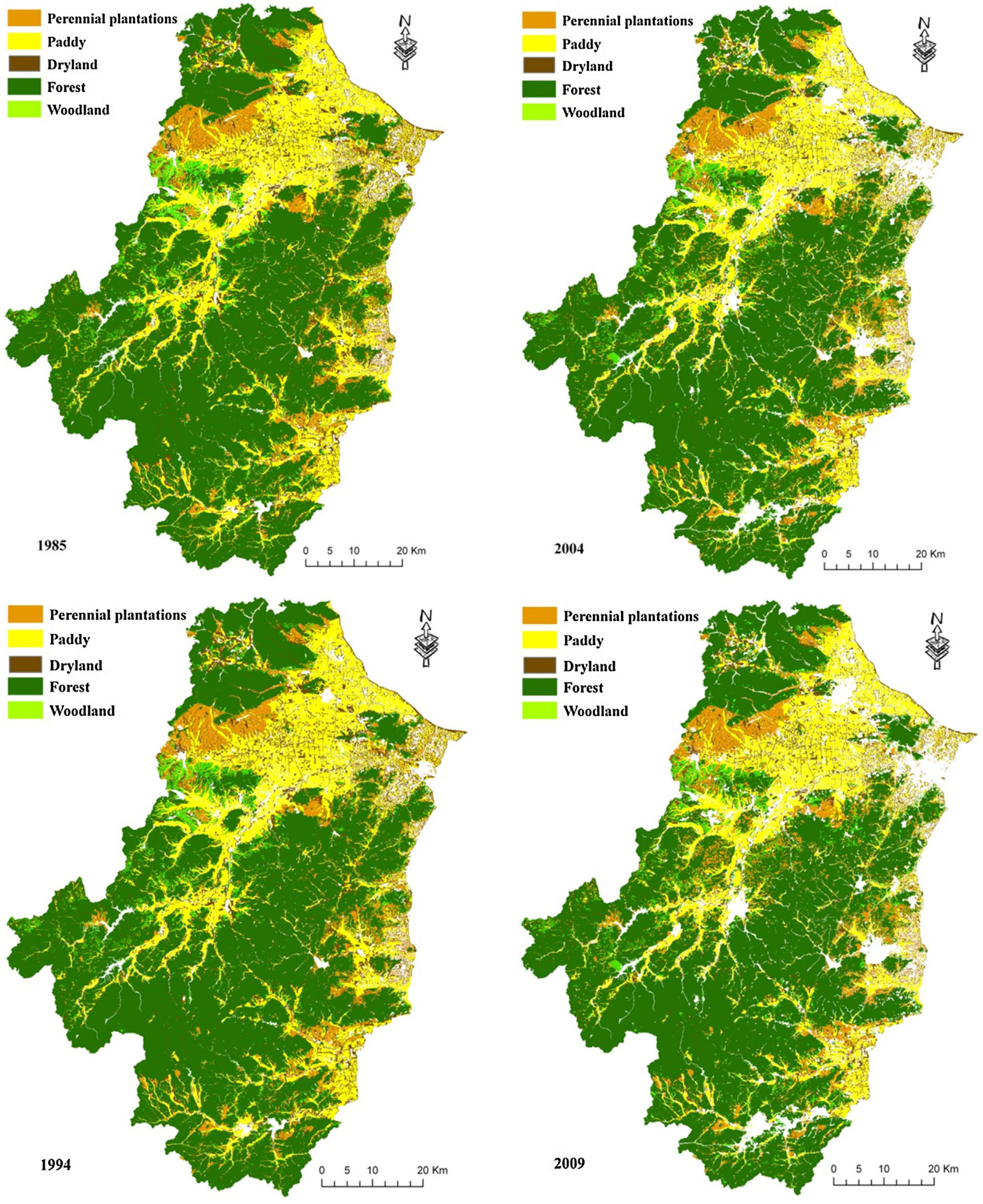

Fig. 2. Patterns of vegetated landscape types in Tiaoxi watershed (China) from 1985 to 2009.

et al., 2009). Scholars proposed different principles for metrics selection (Leitão and Ahern, 2002; Weng, 2007; Tian et al., 2011; Su et al., 2014b), which can be summarized into three key criteria: (1) metrics can represent different aspects of landscape characteristics (e.g., edge, size, shape, connectivity, and diversity); (2) metrics should not be highly redundant; (3) metrics should be documented in related studies.

Following these three principles, we first collected a set of 36 landscape level metrics and 32 class level metrics based on literature review. These metrics covered different aspects of landscape characteristics: area, edge, density, shape, isolation, interspersion, contagion, and diversity. All the metrics were subjected to the *Shapiro–Wilk* test for normal distribution, *F* test for variance homogeneity, and standard deviation model for standardization. Pair-wise correlations were then calculated among these metrics using Pearson's correlation analysis. On the condition that absolute value for correlation coefficients between two metrics equaled or exceed 0.9, we discarded one of them (Griffith et al., 2000). Varimax rotated principal component analysis (PCA) was then used to calculate the eigenvalues for each component and the loadings for each metric (Khalyani et al., 2013). Components whose eigenvalues exceed 1.0 and metrics with high loadings (>0.75) in each component were retained (Cumming and Vernier, 2002).

We finally obtained a set of class-level metrics (class area (CA), patch density (PD), mean proximity index (MPI), and aggregation index (AI)), and a set of landscape-level metrics (total area (TA), PD, landscape shape index (LSI), connectance index (CONNECT), and Shannon's diversity index (SHDI)). At the class level, CA shows the areal changes of different vegetated landscape types; PD, MPI, and AI denote fragmentation, isolation, and aggregation, respectively (Leitão and Ahern, 2002). At landscape level, TA demonstrates vegetated area; PD, LSI, CONNECT, and SHDI reflect fragmentation, irregularity, connectivity, and diversity, respectively (Leitão and Ahern, 2002). Patch Analyst 4.0 (Rempel, 2008) facilitated the metric analysis in this study.

2.4. Selection of socioeconomic indicators

Socioeconomic indicators were selected based on four principles: (1) they were able to capture different aspects of socioeconomic development (demography, economy, and social activities); (2) they have been applied to indicate China's socioeconomics (Gong et al., 2013; Long et al., 2009; Su et al., 2012; Xu et al., 2014); (3) they have potential impact on landscape pattern changes; and (4) data for indicator calculation were available. The procedure for indicator selection was similar to that for metric selection described in Section 2.3.

We first selected indicators based on literature review for each category (demography, economy, social activities). Five variables were selected to indicate demography: total population, total number of household, population density, non-agricultural population proportion, and total number of resident population. Gross domestic product, total industrial output, per capita net income of rural households were the most popular economic indicators of landscape pattern changes (Gong et al., 2013; Kromroy et al., 2007; Long et al., 2009; Su et al., 2014b; Szantoi et al., 2012). Economic structural transformation was usually described by the proportion of secondary industry and the proportion of tertiary industry. Two more indicators were selected for economy, since these factors contribute to economic growth: total fiscal revenue and foreign investment. Daily life requires the construction of the living and physical infrastructure, which would exert impacts on landscape pattern changes (Liu et al., 2014; Su et al., 2014c). We selected seven variables to indicate social activities: investment in fixed assets, road mileage, rural community built-up land area, number of employees, passenger volume, freight volume, and total retail sales of consumer goods.

As stated above, the original set included 19 socioeconomic indicators: five for demography, seven for economy, and seven for social activities. Correlation analysis and PCA were further applied to select the most important indicator. The final set included nine indicators: total population (TP), proportion of non-agricultural population (PNAP), gross domestic product (GDP), total industrial output (TIO), proportion of tertiary industry (PTI), investment in fixed assets (IFA), road mileage (RM), total retail sales of consumer goods (TRSCG), per capita net income of rural households (PCNIRH). We were accessed to the official statistical database by local government. All the statistical data were collected at rural community (village and town) level every year from 1985 to 2009.

2.5. Statistical analysis

Scatter-regression plot was employed to display the trend for each metric. It cannot only exhibit the original values of metrics, but also show the overall tendency. Multiple linear regression analysis was applied to analyze the socioeconomic drivers of vegetated landscape pattern changes. For each regression, one metric acted as independent variable and the selected potential socioeconomic drivers were the predictors. To tackle with potential problem of multicollinearity, the predictors were entered and removed in a stepwise manner, until no justifiable reason could be based on to enter or remove more. Before performing regression, all the variables were normalized and standardized by the standard deviation model.

3. Results and discussion

3.1. General socioeconomic development

Tiaoxi watershed experienced rapid socioeconomic development during the 25 years (Fig. 3). Demographic factors (TP and PNAP) showed linear increasing trend. TP grew from 2.09 million to 19.32 million, with a net growth of 8.2%. PNAP saw a net growth of 91.0%, increasing from 15.2% to 29.1%. These figures denoted that individuals in Tiaoxi watershed made their living less and less on traditional agriculture, forestry, fishing, and hunting. The exponential growth of GDP and TIO suggested the economic and industrial developments were accelerated during the study period. PCNIRH also experienced exponential growth within the study period. It not only reflected the economic development of the study area, but also marked the improvement of people's daily life. PTI displayed linear increasing tendency, implying that tertiary industry had more and more shares in total values of gross domestic product. RM tripled from 1985 to 2009, denoting the intensive road construction in the study area. The other two social indicators (IFA and TRSCG) exhibited an exponential growing trend, indicating life quality of the local dwellers had been improved.

3.2. Landscape-level vegetated landscape pattern changes

From 1985 to 2009, TA presented linear declining trend (Fig. 4), revealing that vegetated area has been gradually depleted. The net loss of vegetated area amounted to 45,123.9 ha, decreasing from 549,838.6 ha in 1985 to 504,714.7 ha in 2009. The decline of CONNECT suggested that connectivity among vegetated landscape patches was reduced. The other three metrics exhibited opposite tendency. Increases in PD and LPI implied that vegetated landscapes became more fragmented and irregular. Driven by the rapid socioeconomic development, Tiaoxi watershed experienced profound settlement expansion (Su et al., 2011), occupying a large number of vegetated area. These expanded settlements were fragmented and irregular, and dispersed among vegetated landscape patches in a disorder manner (Su et al., 2011). Such patterns resulted in the declined connectivity and increased fragmentation and irregularity of vegetated landscapes. An increasing trend was found for SHDI, denoting that vegetated landscapes became more diverse (Fig. 4). The decreasing dominance of some vegetated landscape types should explain the higher diversity.

3.3. Class-level vegetated landscape pattern changes

In terms of areal changes, the five vegetated landscape types can be divided into two groups (Fig. 5). Class area of paddy, dryland, and forest decreased with time, while that of woodland and perennial plantations increased temporally. Comparing the slope of simulation curve, it can be seen that the decreasing rates of paddy and dryland were higher than that of forest. Area of perennial plantations increased at a more rapid pace than woodland. The loss of paddy, dryland, and forest has been observed globally and is a common consequence of urban expansion at the

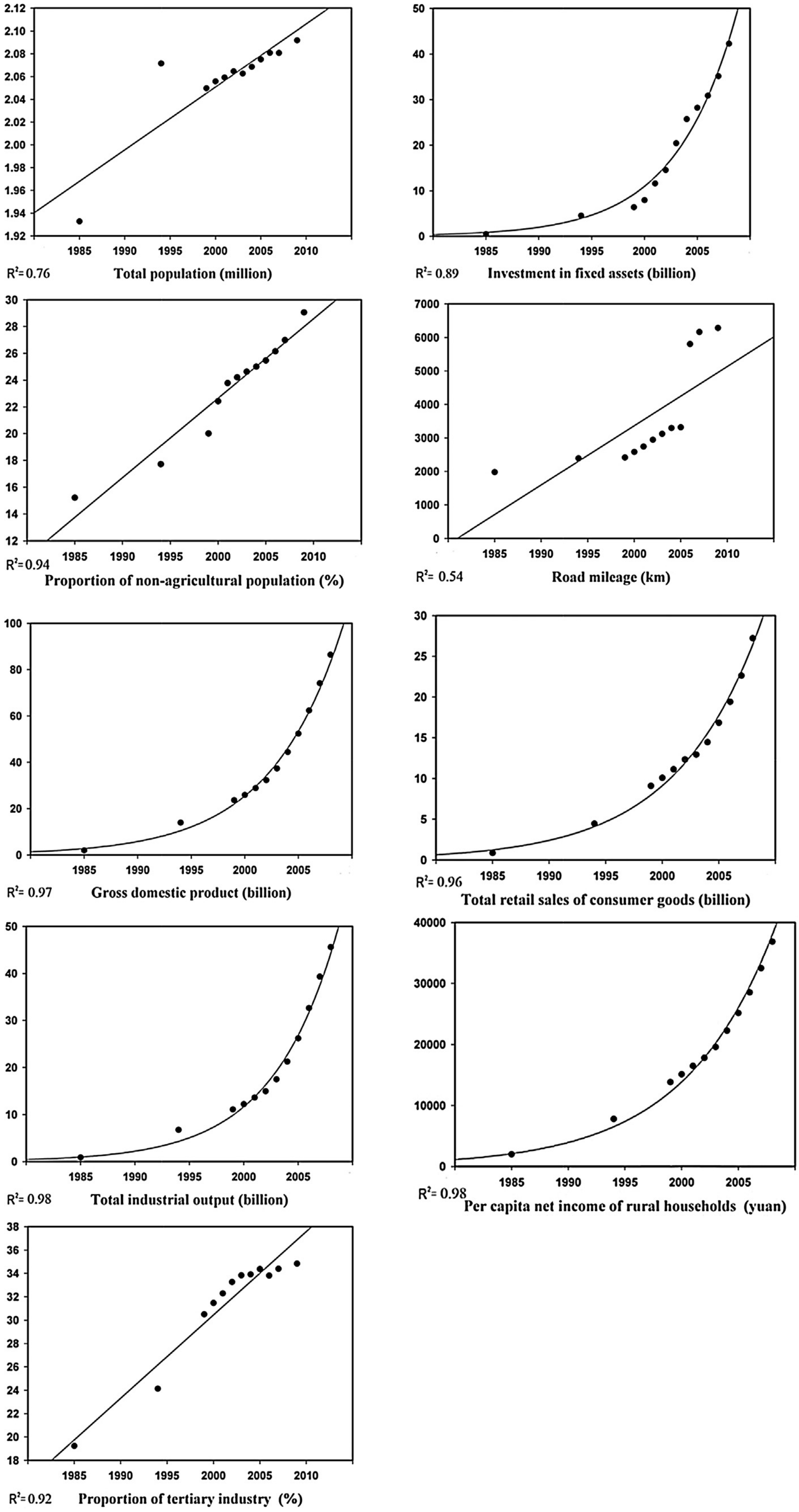

Fig. 3. Scatter–regression plot of socioeconomic variables changes from 1985 to 2009.

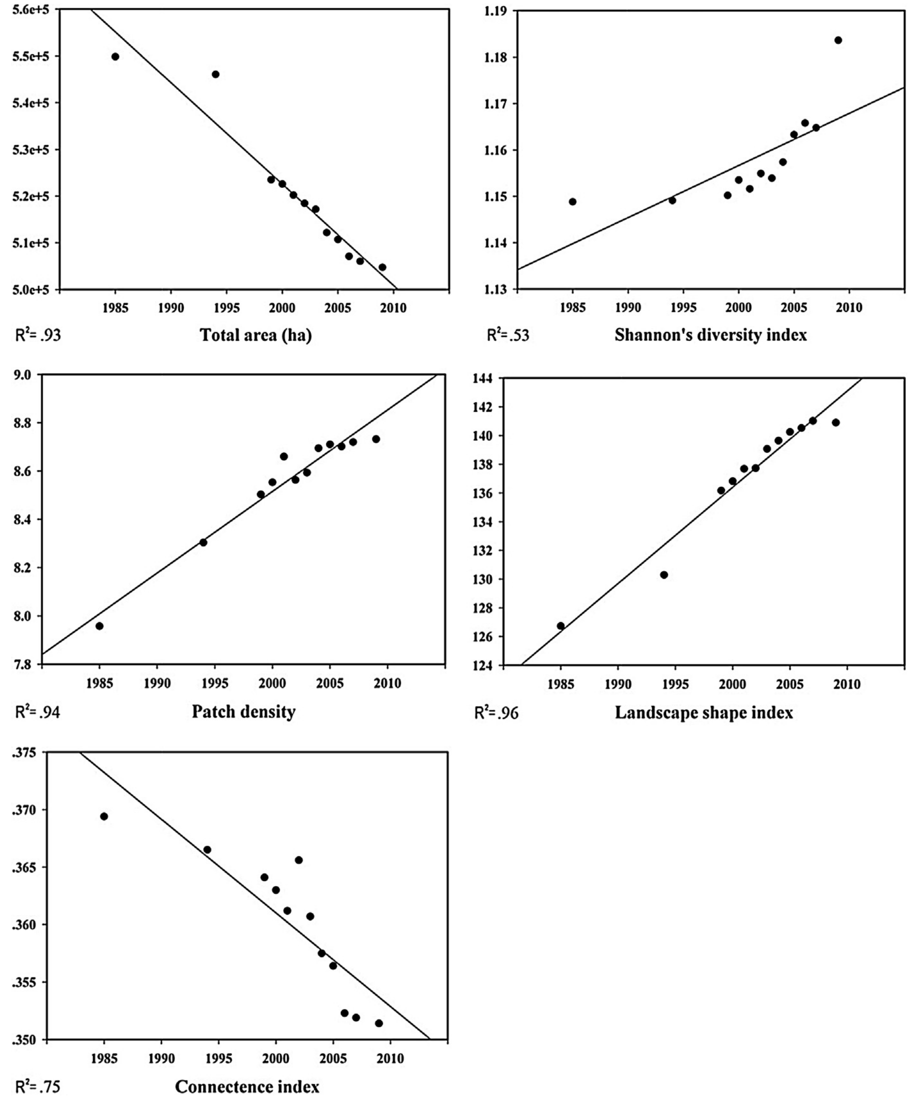

Fig. 4. Scatter–regression plot of landscape level metrics for vegetated pattern changes from 1985 to 2009.

rural–urban interface (Torres, 2007; Turner et al., 2007; Huang et al., 2009; Miller, 2012). Most new development in this watershed concentrated along transportation routes and areas with low slope, considering the physical suitability for expansion (Su et al., 2011). New expansion gradually occupied paddy and dryland in the flat areas within the watershed (Su et al., 2011). Mining-driven sprawl accounted for the forest loss occurring along the road. Introduction of profitable cash plantations was a major approach to the achievement of economic growth in rural areas (Manivong and Cramb, 2008). Encouraged by the success of some pioneers, most farmers acknowledged the promising profit of woodland and perennial plantations (Su et al., 2014a). A portion of paddy and forest were replaced by woodland and perennial plantations. Such land use choice contributed to the increasing areal changes of woodland and perennial plantations.

All the five vegetated landscape types exhibited linear PD increases and MPI decreases (Fig. 5). These results demonstrated that increasing fragmentation and isolation would be expected among all vegetated landscape types. Settlement sprawl generated growing smaller vegetated landscape patches, leading to the increases in fragmentation and isolation. In Tiaoxi watershed, the establishment of woodland and perennial plantations was farmers'spontaneous behavior, since there were no officially regulated land use plans or guidance for cultivation that farmers could follow (Su et al., 2014a). The newly planted woodland and perennial plantations were highly fragmented and disorderly in space. The disordered distribution of perennial plantations divided original, larger, and intact paddy and forest patches into smaller and isolated patches (Su et al., 2014a), fragmenting paddy and forest. All these led to it that the increasing rate of fragmentation was higher for perennial plantations, paddy, and forest. Dryland experienced faster isolation declines. It could be related to its smaller area, since MPI was calculated using the nearest neighbor statistics.

Trend of AI was similar to that of CA (Fig. 5), suggesting that paddy, dryland, and forest became less aggregated. Lower landscape aggregation denoted a pattern of random distribution of small patches (He et al., 2000). Decreases of aggregation for paddy, dryland, and forest should be linked with shrinkage and fragmentation. Aggregation of perennial plantations and woodland increased with time, which should be related to the expansion of these two vegetated landscape types. Aggregation of woodland increased more rapidly than perennial plantations, which implied that woodland became more systematically distributed in space.

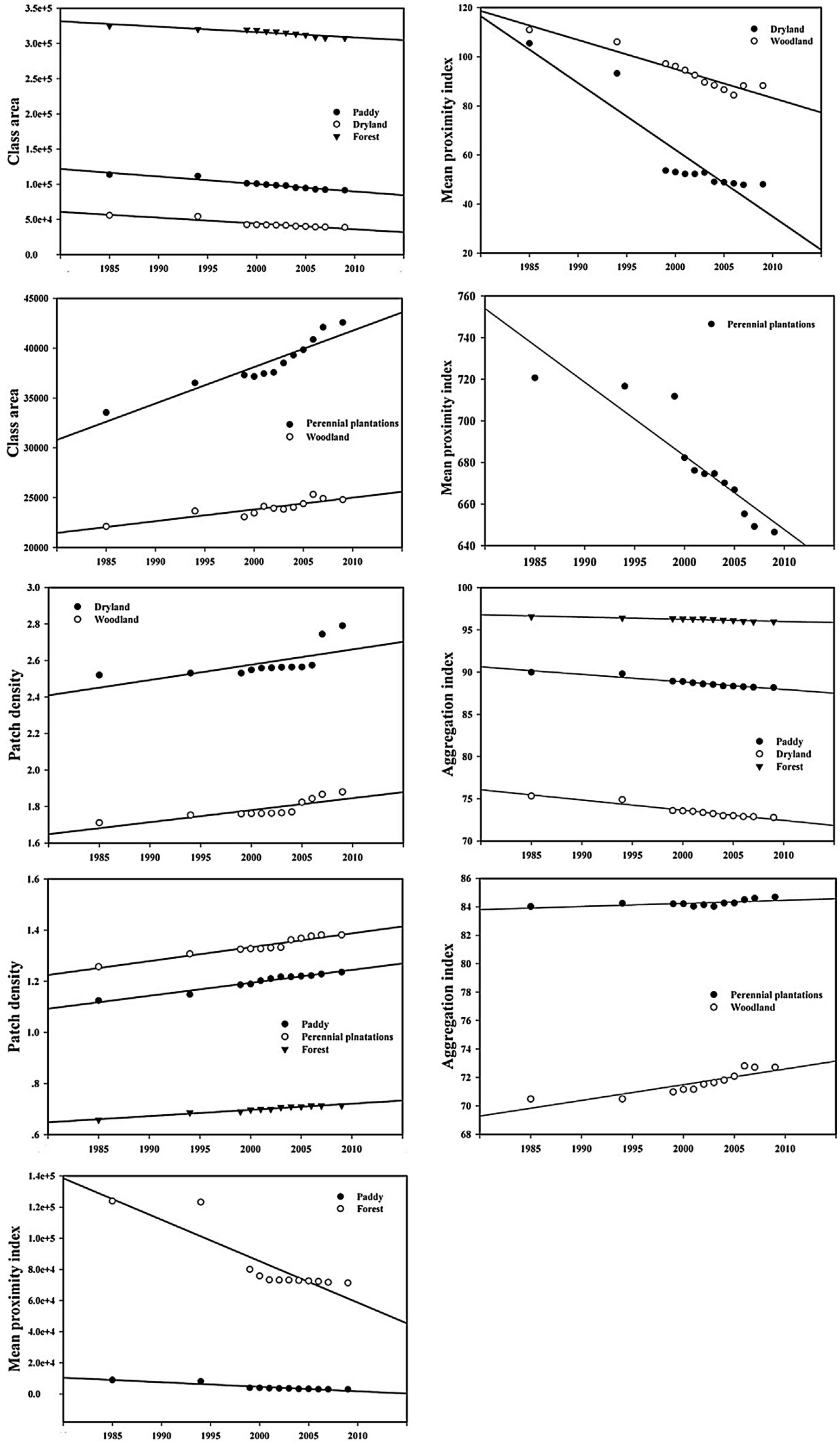

Fig. 5. Scatter–regression plot of class level metrics for vegetated pattern changes from 1985 to 2009.

Topology played an important role in shaping landscape patterns (Hou and Walz, 2013). Woodland generally concentrated in areas with gentle slope, while perennial plantations could be established in both flat and steep areas (Su et al., 2014a). Woodland was less randomly distributed than perennial plantations during expansion, and its increasing rate of AI value was therefore relatively higher.

3.4. Socioeconomic drivers of vegetated landscape pattern changes

Relationships between vegetated landscape pattern changes and socioeconomic development at landscape level were shown in Table 1, and those at class level were demonstrated in Table 2. TP was a significant predictor for TA and CA of dryland and

Table 1
Relationships between landscape-level vegetated landscape pattern changes and socioeconomic development.

Dependent	Independent	Regression	R^2
TA	TP, PCNIRH	$Y = -0.62 \times \text{TP} - 0.49 \times \text{PCNIRH} + 1.07$	0.71^{**}
PD	TP, PTI	$Y = 0.21 \times \text{TP} + 0.57 \times \text{PTI} + 7.95$	0.65^{**}
LSI	PTI, PCNIRH	$Y = 11.49 \times \text{PTI} + 3.55 \times \text{PCNIRH} + 126.5$	0.62^{**}
CONNECT	RM	$Y = -0.02 \times \text{RM} + 0.37$	0.52^{**}
SHDI	RM	$Y = 0.031 \times \text{RM} + 1.15$	0.50^{**}

** $p < 0.01$.
Abbreviations: total area (TA); patch density (PD); landscape shape index (LSI); connectance index (CONNECT); and Shannon's diversity index (SHDI); total population (TP); proportion of tertiary industry (PTI); road mileage (RM); per capita net income of rural households (PCNIRH).

forest, and PNAP was a significant explanatory factor for CA of paddy. These relationships demonstrated that demographical factors were important contributors to vegetated areal loss at both landscape level and class level (paddy, dryland, and forest). More specifically, the influence of population structure change was only significant at class level. Increasing demand for resources to sustain living, production, and food is expected as population grows (Döös, 2002; Long et al., 2009; Gong et al., 2013). Decreases in paddy, dryland, and forest area occurred in correspondence to the rapid population growth in the study area. The need for more residential space spurred expansion and increased vegetated landscape fragmentation, which contributed to the significant correlations between TP and PD (Table 1). Besides, TP was significantly correlated with PD and MPI for forest at class level (Table 2). It implied that population could be indicative of the fragmentation and isolation of forest patches in peri-urban area. Such discovery was different from that of Gong et al. (2013), in which population was found to be an insignificant predictor of urban forest fragmentation. In most cases, population was an indirect influential factor of landscape pattern changes, since it exerted their impact through built-up land construction (Livingston et al., 2003; Su et al., 2012). High-rise department in compact urban areas can accommodate more people than single houses in peri-urban areas. Consequently, more built-up land is needed when population grows in peri-urban regions.

PCNIRH presented negative correlation with TA (Table 1) and CA of forest, but showed opposite correlation with CA of woodland and perennial plantations (Table 2). Such results demonstrated that income increase was indicative of the declines of vegetated area and forest coverage, but increases of woodland and perennial plantations. These discoveries differed from those for urban areas in previous related report, since income was always a positive indicator of vegetation coverage and negative indicator of fragmentation for urban areas (Luck et al., 2009; Szantoi et al., 2012; Gong et al., 2013). The inconsistence could be attributed to the different socioeconomic conditions and their interactions with land use practice between urban and peri-urban areas. Urban residents desire to live in areas with higher vegetation coverage. Rural households pursue more profit by conversing paddy, dryland, and forest to woodland and perennial plantations. This land use practice also contributed to the positive influence of PCNIRH on AI of woodland and negative impact of PCNIRH on AI of dryland and forest.

No metrics were significantly correlated with GDP (Tables 1 and 2), suggesting that GDP exerted insignificant impacts on vegetated landscape pattern changes in peri-urban areas. This result was not accorded with previous studies in urban settings, where GDP was regarded as key indicator of vegetated landscape pattern changes (Kromroy et al., 2007; Long et al., 2009). Instead of GDP, PTI was a strong predictor in our study. PTI was correlated with PD and LSI at landscape level (Table 1), signifying the role of tertiary industry development on vegetated landscape fragmentation and irregularity. At the class level, PTI had positive relationships with PD of paddy and forest, but negative relationships with AI of paddy and dryland (Table 2). It could be inferred that these three vegetated landscape types would become more fragmented and less aggregated as tertiary industry develops. PTI was also a good indicator of vegetated landscape isolation, since it was significantly correlated with MPI of paddy, dryland, perennial plantations, and woodland (Table 2). Specifically, tertiary industry development would result in more isolation among paddy and dryland patches, but less isolation among perennial plantations and woodland patches. Tertiary industry development reflects a complex changing process of service sectors and lifestyle. This process stimulates demand for more urban land and results in the intrusion into paddy, dryland, and forest. This contributed to

Table 2
Relationships between class-level vegetated landscape pattern changes and socioeconomic development.

Vegetation type	Dependent	Independent	Regression	R^2
Paddy	CA	PNAP	$Y = -1.08 \times \text{PNAP} + 0.98$	0.74^{**}
	PD	PNAP, PTI	$Y = 0.06 \times \text{PNAP} + 0.06 \times \text{PTI} + 1.12$	0.69^{**}
	MPI	PTI	$Y = -7511.71 \times \text{PTI} + 8882.82$	0.57^{**}
	AI	PTI, RM	$Y = -1.46 \times \text{PTI} - 0.56 \times \text{RM} + 90.11$	0.61^{**}
Dryland	CA	TP, PTI	$Y = 0.30 \times \text{TP} - 1.26 \times \text{PTI} + 1.01$	0.63^{**}
	PD	RM	$Y = 0.25 \times \text{RM} + 2.48$	0.53^{**}
	MPI	PTI	$Y = -61.24 \times \text{PTI} + 106.23$	0.57^{**}
	AI	PTI, PCNIRH	$Y = -2.06 \times \text{PTI} - 0.67 \times \text{PCNIRH}$	0.52^{**}
Perennial plantations	CA	PCNIRH	$Y = 0.97 \times \text{PCNIRH} + 0.06$	0.54^{**}
	PD	PCNIRH	$Y = 0.52 \times \text{PCNIRH} + 1.27$	0.60^{**}
	MPI	PNAP, PTI	$Y = -117.14 \times \text{PNAP} + 31.23 \times \text{PTI} + 723.67$	0.61^{**}
	AI	RM	$Y = 0.55 \times \text{RM} + 84.06$	0.57^{**}
Woodland	CA	PCNIRH	$Y = 0.84 \times \text{PCNIRH} + 0.15$	0.58^{**}
	PD	RM	$Y = 0.17 \times \text{RM} + 1.72$	0.57^{**}
	MPI	PTI	$Y = 19.31 \times \text{PTI} + 111.71$	0.51^{**}
	AI	PCNIRH	$Y = 2.77 \times \text{PCNIRH} + 70.21$	0.59^{**}
Forest	CA	TP, PCNIRH	$Y = -0.43 \times \text{TP} - 2.74 \times \text{PCNIRH} + 1.91$	0.68^{**}
	PD	TP, PTI	$Y = 0.02 \times \text{TP} + 0.03 \times \text{PTI} + 0.66$	0.65^{**}
	MPI	TP	$Y = -28874.96 \times \text{TP} + 122127.28$	0.56^{**}
	AI	PCNIRH	$Y = -1.68 \times \text{PCNIRH} + 96.57$	0.53^{**}

** $p < 0.01$.
Abbreviations: class area (CA); patch density (PD); mean proximity index (MPI); and aggregation index (AI); total population (TP); proportion of non-agricultural population (PNAP); proportion of tertiary industry (PTI); road mileage (RM); per capita net income of rural households (PCNIRH).

the significant impact of PTI on vegetated landscape patterns at class level. These results implied that peri-urban vegetated landscape pattern changes were more sensitive to tertiary industry development rather than the total economic growth.

RM was the only variable significantly associated with CONNECT and SHDI (Table 1). It suggested that road construction was the primary influential factor of vegetated landscape connectivity and diversity. At the class level, RM was positively correlated with PD for dryland and woodland (Table 2), which should be related with the spatial position of the two vegetated landscape types. RM was negatively correlated with AI of paddy (Table 2), which denoted that aggregation of paddy patches could be significantly reduced by road construction. These findings supported previous argument that road played a critical role in governing vegetated landscape pattern changes (Liu et al., 2014). The abundant vegetated landscape types were disturbed by road construction and broken into small patches with complex boundaries (Fu et al., 2010; Serrano et al., 2002). Therefore, road construction can result in vegetated landscape fragmentation and further lead to declined connectivity and increased diversity.

4. Conclusions

This paper used remote sensing to monitor the dynamic changes of vegetation from 1985 to 2009 in a typical per-urban region in Chinese eastern coast. A set of metrics was employed to describe vegetated landscape patterns on two spatial levels. At landscape level, increasing fragmentation, irregularity, and diversity, as well as declining total area and connectivity were identified. At class level, increasing fragmentation and isolation were found for all vegetated landscape types. Paddy, dryland, and forest decreased in area and aggregation, while woodland and perennial plantations presented opposite trend. More specifically, the changing rates varied with vegetated landscape types. The absolute area, spatial position associated with topology, and land use practices should account for the different landscape characteristics among the five vegetated landscape types.

The application of landscape metrics permitted the description of vegetated landscape patterns using numerical values. Compared to qualitative description, such data were easier to monitor, analyze, and compare. Moreover, the changing trends of different vegetated landscape types and the disruptions from socioeconomic development can be verified. Vegetated landscape pattern changes occur at different spatial levels, and present different characteristics at landscape level and class level. Description at one certain level cannot fully capture the characteristics of vegetated landscape pattern changes. The simultaneous application of landscape-level and class-level metrics therefore facilitated the understanding of the general vegetated landscape pattern changes, and transformation of principal vegetated landscape types.

It is helpful to have reliable indicators to envisage future vegetated landscape development. The paper discussed three categories of socioeconomic indicators (demography, economy, and social activities), which were set into relation to selected vegetated landscape pattern changes. Our results suggested that not all of the socioeconomic variables were good indicators of vegetated landscape pattern changes. Generally, population growth (TP), tertiary industry development (PTI), income increase (PCNIRH), and road construction (RM) were the primary influential factors of vegetated landscape pattern changes at both landscape level and class level. PNAP was relevant with vegetated landscape metrics only at the class level. It can be concluded that population structure change was a significant driver of class level vegetated landscape pattern changes. The socioeconomic drivers of vegetated landscape pattern changes differed from those for urban areas. The inconsistence could be attributed to the different socioeconomic conditions and their interactions with land use practice between urban and peri-urban areas. These obtained indicators allow for drawing predictions on the dynamics of vegetated landscape patterns and making preventive measures in peri-urban areas. Our study therefore contributed to the identification of key socioeconomic indicators influencing vegetated landscape pattern changes in peri-urban regions.

Several shortcomings still exist in this paper. Firstly, the unit for analysis was the entire watershed, and the variations of vegetated landscape patterns within the watershed remained unknown. Secondly, the remotely sensed data was of relatively low resolution, and we cannot interpret different species. For example, forest was constituted of pine, bamboo, nursery, and other broadleaf or coniferous species. Thirdly, household level socioeconomic drivers were not examined. The potential impacts from household factors on vegetated landscape patterns should be quantified in the future.

It should be mentioned that urban land area, which was a popular socioeconomic indictor, was excluded from analysis. We discarded the urban land area variable, because it was a direct variable for landscape pattern changes, while all of the other variables were indirect variables. Further study should be carried out to investigate the complex interactions of direct drivers and indirect drivers and their influences on vegetated landscape pattern changes. Since socioeconomics would continue to develop in the peri-urbanizing Tiaoxi watershed, it is vital that vegetated landscape patterns continue to be monitored for better understanding of how socioeconomics will influence peri-urban vegetation. The following study should concentrate on the spatial interactions between human activities and vegetated landscape patterns, the impacts of landscape pattern changes on the vegetated ecosystem functions, and the response of different vegetated landscape types. In particular, the links between socioeconomic drivers, landscape pattern changes, and their impacts on ecosystems at different scales should be examined.

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