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Spatio-temporal dynamic patterns of farmland and rural settlements in Su–Xi–Chang region: Implications for building a new countryside in coastal China

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ABSTRACT

This paper analyzes the spatio-temporal dynamic patterns of farmland and rural settlements from 1990 to 2006 in Su–Xi–Chang region of coastal China experienced dramatic economic and spatial restructuring, using high-resolution Landsat TM (Thematic Mapper) data in 1990, 1995, 2000 and 2006, and socio-economic data from both research institutes and government departments. To examine the spatial patterns of farmland and rural settlements and their change over time, a set of pattern metrics that capture different dimensions of land fragmentation was identified. The outcomes indicated that, to a large extent, land-use change from 1990 to 2006 in Su–Xi–Chang region was characterized by a serious replacement of farmland with urban and rural settlements, construction land, and artificial ponds. Population growth, rapid industrialization and urbanization are the major driving forces of farmland change, and China's economic reforms played an important role in the transformation of rural settlements. China's "*building a new countryside*" is an epoch-making countryside planning policy. The focuses of building a new countryside in coastal China need to be concentrated on protecting the farmland, developing modern agriculture, and building "clean and tidy villages." Rural construction land consolidation and cultivated land consolidation are two important ways to achieve the building objectives. The authors argue that it is fundamental to lay out a scientific urban–rural integrated development planning for building a new countryside, which needs to pay more attention to making the rural have certain functions serving for the urban. In addition, the cultural elements of idyll and the rural landscape need to be reserved and respected in the process of building a new countryside in coastal China, instead of building a new countryside, which looks more like a city.

Introduction

Much importance is attributed to the search for knowledge about the impact of human societies on our environment as rapid population growth and economic development intensify the stresses that human beings place on the biosphere and ecosystems (Omenn, 2006). Under the circumstances, land change science, an interdisciplinary field seeks to understand the dynamics of land use and land cover (LULC) as a coupled human–environment system to address theory, concepts, models, and applications relevant to environmental and societal problems, has emerged as a fundamental component of global environmental change and sustainability research (GLP, 2005; Turner et al., 2007). Recently, issues related to LULC change have attracted interest among a wide variety of researchers, ranging from those who favor modeling spatio-temporal patterns of land conversion to those who try to understand the coupled system—causes, impacts, and consequences (Verburg et al., 1999; Brown et al., 2000; Theobald, 2001; Irwin and Geoghegan, 2001; Veldkamp and Lambin, 2001; Krausmann et al., 2003; Veldkamp and Verburg, 2004; Irwin and Bockstael, 2007).

Remote sensing (RS) and geographic information systems (GIS) have been recognized as powerful and effective tools for detecting the spatio-temporal dynamics of LULC (Fazal, 2000; Weng, 2002; Herold et al., 2003; Nagendra et al., 2004; Gao et al., 2006; Huang et al., 2007). Usually, spatially explicit time series of land-use change can be developed based on RS (Moglen and Beighley, 2002; Poyatos et al., 2003; Himiyama, 1998). There are widely

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used approaches of change detection and statistical analysis, which enable us to discover the structural variation among different land-cover patterns and to diagnose land-use change based on time-series socio-economic data (Liu et al., 2003a; Kaufmann and Seto, 2001; Krausmann et al., 2003; Verburg et al., 1999; Aspinall, 2004; Xie et al., 2005; Long et al., 2007a). These time-series analyses of land-use change and the identification of its driving forces can provide decision-makers with important information for sustainable land management and regional development.

Since China initiated economic reforms and an open-door policy in 1978, tremendous changes in China's development philosophy and regional economics have occurred (Wei and Fan, 2000). As a result, many coastal regions of China such as the Yangtze River Delta region and Pearl River Delta region experienced dramatic economic and spatial restructuring, which resulted in tremendous land-use change (Streets et al., 1995; Lin, 2001; Weng, 2002; Seto and Kaufmann, 2003; Li and Yeh, 2004; Long et al., 2007a). Land-use changes, while restricted by physical conditions, are mainly driven by socio-economic factors, and they can be mainly characterized by the changes of farmland and construction land, which are tightly inter-related with human production activities (Long et al., 2007b). In China's rural areas, farmland and rural settlements[1] are the two most important land-use types depicting rural development.

The conversion of farmland to non-agricultural use during the last two decades in China has been arguably the most widespread in the country's history, and in coastal China the process has been more intense than any other regions (Yang and Li, 2000; Li and Wang, 2003; Ho and Lin, 2004; Lichtenberg and Ding, 2008). The accelerated industrialization and urbanization following economic reforms and population increases have greatly affected land-use change through the increase of rural settlements and urban sprawl (Long et al., 2007a; Xie et al., 2007b). The fragmentation of farmland can be also observed due to construction on land of the countryside (Sargeson, 2002; Lin and Ho, 2003). In addition, the adoption of market principles has resulted in the internal restructuring of agricultural land use from traditional paddy production to more diversified agricultural activities such as growing cash crops, fruits and aquaculture (Heilig, 1999; Li and Yeh, 2004). A study of Landsat photographs of one south Jiangsu region revealed that because rural settlements are scattered and use a large amount of land, the shift in land use has not been restricted to a few major cities but has been widely dispersed (Ho and Lin, 2004). Rural housing development may have contributed greatly to the loss of farmland, and there is considerable debate on the extent and magnitude of Chinese rural land-use change since the onset of reforms in 1978 (Sargeson, 2002; Xu, 2004; Long et al., 2007b), largely because of the complexity of land-use change regarding its process, dynamic and driving forces (Theobald, 2001; Cai, 2001; Burgi and Turner, 2002; Lambin et al., 2001). With the continuous growth of China's economy, massive farmland loss for the benefit of market farming and non-agricultural development may occur without appropriate planning and management of existing land resources in coastal China.

Competition between agricultural and non-agricultural land uses is at its most intense at the interface between the urban and the rural, frequently resulting in a succession of land uses at any one location over time, and the changing directions of agricultural policy and *countryside planning policies* are the main factors driving such successions as well as the fluctuating strengths of urban and rural economies (Robinson, 2004, p. 206). Changes in land and ecosystems and their implications for global environmental change and sustainability are a major research challenge for the human–environmental sciences (Omenn, 2006; Turner et al., 2007). While there are numerous studies analyzing the loss of farmland in China due to urban sprawl and rural settlements construction (Sargeson, 2002; Liu et al., 2003b, 2005a; Xu, 2004; Tian et al., 2005, 2007; Long et al., 2007b), China's rural land-use change and its policy dimensional analysis has found much less attention. The aims of this paper are: (1) to briefly introduce China's "building a new countryside," an epoch-making countryside planning policy; (2) to examine the dynamic patterns of rural land (focused on farmland and rural settlements) in Su–Xi–Chang region of coastal China experienced dramatic economic and spatial restructuring, using high-resolution Landsat TM (Thematic Mapper) data in 1990, 1995, 2000 and 2006, and socio-economic data from both research institutes and government departments; and (3) to discuss some of the major implications for building a new countryside in coastal China.

China's "building a new countryside" policy

Usually, the development of countryside will be paid more attention to when the industrialization and urbanization of a country attain a certain phase, in the form of laying out a series of favorable policies. However, the segmentation of rural policy has become more and more unsustainable with the progress of social and economic restructuring, and a more integrated rural policy needs to be developed because of the diverse character of the contemporary countryside (Woods, 2005, p. 131). For example, several general terms to all government bodies having a duty of care in relation to the countryside were referred in the Countryside Act (1968) of UK (Mather et al., 2006). The 'Rural White Papers' for England, Scotland and Wales (1995) were integrated statements of the government's policies on a wide range of issues relating to rural areas, from agriculture to telecommunications, housing to village halls, and forestry to sport (Hodge, 1996; Woods, 2005). The policies and funds associated with the basic agricultural laws of 1960 and 1962 have transformed many aspects of the French countryside over the past half-century (Clout, 2006). In the 1970s, South Korea carried out "New Countryside Campaign" to speed up the development of rural areas.[2] Japan implemented similar campaign in the 1960s, and established corresponding laws and regulations, which were in favor of rural development.[3]

At present, both rural development and urban development in China are in a transition period—the transformation of a traditional agricultural society into a modern industrial and urban society, and the economy is changing from a traditional planned economy to a modern market system (Long et al., 2007b). In the process of industrialization and urbanization since the economic reforms of 1978, agriculture and the countryside have made a big contribution to, to some extent, the huge sacrifices for the development of industries and the cities in China. As a result, a series of problems that ham-

[1] Rural settlements, also called rural housing land, refers to the land utilized by rural residents for dwelling and living, i.e. land for building house and other structures or affiliated facilities (Long et al., 2007b). Since the early 1980s, the household responsibility system has provided strong incentives for rural towns and villages to diversify and grow their economies by developing nonagricultural enterprises, which often involves small-scale, individual, privately owned, nonagricultural land use, termed "rural construction" in official Chinese statistical yearbooks, with most construction registered as *rural housing*. But the functional uses of such rural construction are diverse; many individual houses are in mixed use, based on small factories, craft and other retail shops, restaurants, and related privately owned and operated businesses (Xie et al., 2007a). In coastal China it is a universal phenomenon.

[2] The new countryside campaign of South Korea (http://news.xinhuanet.com/world/2006-02/16/content_4189182.htm).

[3] "New countryside campaign" of South Korea and "55 years system" of Japan (http://dycj.ynet.com/article.jsp?oid=7520089&pageno=3).

per the social and economic development of China occurred (Cai and Smit, 1994a, 1994b; Xu and Tan, 2001, 2002). First, the amount of cultivated land shrunk from 138.38 Mha in 1978 to 122.07 Mha in 2005. Lacking irrigation facilities, many farmers are forced to depend on nature. Both scientific and financial supports on the agricultural sector are weak. All of these make the country's agricultural sector lack a solid foundation for speeding up the social and economic development of China and upgrading people's living standards in the countryside. Second, the income gap between the rural and urban residents has been widened from 2.57 to 1 in 1978 to 3.22 to 1 in 2005 (NBSC, 2006). Third, building a harmonious society demands that the achievements and responsibilities of economic and social development be shared by all people, but the widening gap between urban and rural quality of life will make a harmonious society harder to achieve. Finally, rural residents, who make up nearly 56% of China's population, have contributed less than one-third of the total retail output. The slow increase in farmers' income is hampering the overall economy from developing any faster.

In 2003, China's per capita gross domestic product (GDP) reached 1090 US dollars, which indicates China's economic and social development enters an important, brand-new period. China's fast-growing economy and its stronger position in the global community make itself be ready for providing an atmosphere in which industries support agriculture and cities support the countryside. Furthermore, under the pressures of both the recently widening income gap between the rural and urban population and the problems related to farmers, agriculture and rural areas, the central government of China recently mapped out a long-term development strategy on "building a new countryside," which was established as one of the primary objectives of the 11th Five-Year (2006–2010) Plan, and was expected to solve above problems through coordinating urban and rural development. The Guidelines of PRC's 11th Five-Year Plan for National Economic and Social Development suggests that a new countryside means advanced production, improved livelihood, clean and tidy villages, a civilized social atmosphere and efficient management (SCPRC, 2006). To some extent, the policy of building new countryside in China could be labeled 'post-productivism' (Evans et al., 2002; Mather et al., 2006; Clout, 2006). Not only agricultural production, social and environmental objectives were also now explicitly included within it.

Developing modern agriculture and strengthening the productive forces of the countryside are the major elements of advanced production. First of all, national food security was paid a high attention, and the total grain productive capacity is expected to amount 500 million tons by the end of 2010, through strengthening the productive capacity building of main grain productive areas, and enhancing the yield per unit area, quality and efficiency of grain production. The policies concerning farmland protection will be severely carried out, so as to ensure that the total number of basic farmland[4] not to be cut down, and the quality of that not to be lowered. Improving traditional cultivation techniques and popularizing agricultural standardization are also the important contents of developing modern agriculture and strengthening the productive forces of the countryside. Second, the strategic adjustment of agriculture structure will be promoted by optimizing the industrial structure, the product structure and regional distribution of agriculture.

There is an obvious gap between China's urban and rural areas (NBSC, 2006). In 2005, the disposable income of urban dwellers was 10 493 RMB¥ (US$ to RMB¥: 1–8.0), which is 3.22 times over the per capita net income of Chinese farmers (3255 RMB¥). In order to increase the income of farmers, three measures were put forward in the 11th Five-Year Plan as follows: (1) developing more profitable agricultural products with improved breeds and individual characteristics, and prolonging the industrial chains, such as storage and process, fresh-keeping, transportation, and so on; (2) increasing farmers' non-agricultural income by promoting the structural adjustment and institutional innovation of the Township and Village Enterprises (TVEs); and (3) improving subsidiary policy and lessening farmers' burdens.

In most China's current villages, "dirty, disorderly and bad" is the general impression to the visitors. The "disorderly" was due to two reasons. On the one hand, with the implementing of market based economy after 1978, many farmers were becoming affluent and they began to prefer multi-functional, more comfortable or spacious houses, which resulted in that rural housing has been expanding sharply. Farmers prefer to build their houses in the valleys (instead of the hillside), and they prefer good location and settle close to roads and other available infrastructure. However, there was no scientific village plan. On the other hand, with the progress of urbanization, some village houses are vacant in China's developed rural areas (especially in eastern/coastal China), either because their owners have two or more houses or because they are rural–urban migrators and live permanently in urban area, which resulted in a serious waste of land resources and contributed to the disorder. The blame of "dirty and bad" falls entirely on the lack of process system for the living sewage, living garbage, and non-point sources pollution of excrement and urine from livestock and poultry breeding fields. The objectives of building clean and tidy villages involve: (1) efforts will be made to expand the use of clean fuels such as marsh gas and solar energy in rural areas; (2) the status quo of more than 60% of rural households do not have access to flush toilets will be gradually changed; and (3) to gradually improve the rural houses according to scientific village plan (at present, the houses of nearly 70 million rural residents need to be improved).

Study area

Suzhou, Wuxi and Changzhou three municipalities (usually called "Su–Xi–Chang" region), the study area, is situated at the lower reaches of the Yangtze River in the southern Jiangsu province, one of the fastest growing regions in China (Fig. 1). It covers about 1.76 million ha with average elevation below 50 m. The northern subtropical monsoon climate dominates this region year-round, with average annual temperature of 17.5 °C, mean annual rainfall of 1055 mm, all of which are beneficial for agricultural production. Su–Xi–Chang region has a population of 14.29 million (JSB, 2007), and it is unique because of its high population density. In 2006, the population density in this region was up to 809 persons/km^2, which was much higher than the average population density (137 persons/km^2) of China at the same period (JSB, 2007; NBSC, 2007).

The growth of Shanghai, the most important industrial, commercial and financial center of China, has pushed Su–Xi–Chang region into the industrial age since the early 1980s. Unprecedented changes in the local economy have taken place in recent decades, and by the mid 1980s Su–Xi–Chang region provided a model, also called "Sunan model," for the development of rural industries based on diversified collective enterprises run by the local municipality model (Tan, 1986; Xie et al., 2007a). The term "Sunan model" was originally put forward by the eminent sociologist Fei (1983) to

[4] Basic farmland consists of (Ding, 2003): (1) agricultural production bases (such as crops, cotton, edible oils, and other high quality agricultural products) approved by government; (2) farmland with high productivity and a good irrigation system and that has been exploited; (3) vegetation production bases for large and middle cities; and (4) experimental fields for science and educational purposes.

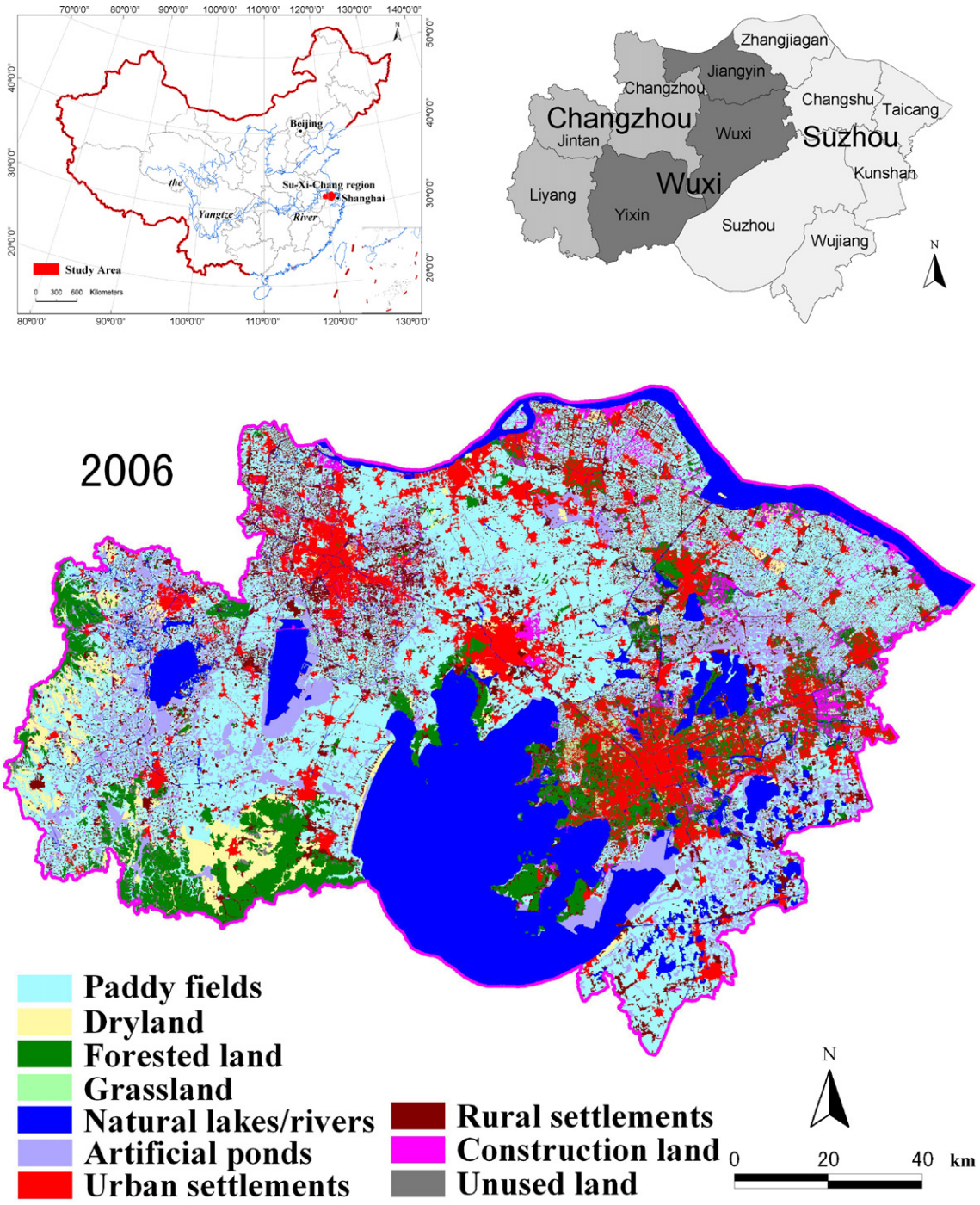

Fig. 1. Location and land use of the study area, Su–Xi–Chang region.

refer to the rapid development of the regional economy in southern Jiangsu (Sunan) based on the massive surge of collectively owned TVEs that prospered from the 1980s to the early 1990s. More specifically, the model refers to the speedy growth of the rural economy in Su–Xi–Chang region of southern Jiangsu where TVEs flourished widely under the direct control of the local county and township governments that ran their enterprises like diversified corporations (Shen and Ma, 2005).

In 2006, the GDP per capita of Su–Xi–Chang region amounted to 67 833 RMB¥, which was much higher than the GDP per capita of China (16 042 RMB¥) at the same period (JSB, 2007; NBSC, 2007). In 2006, the primary industry only provides 2.1% of the total GDP (969 billion RMB¥) in Su–Xi–Chang region; however, 62.6% and 35.3% are provided by the secondary industry and tertiary industry,[5] respectively (JSB, 2007). However, with the growth of population and economic activities, land use in Su–Xi–Chang region has changed dramatically as evidenced by the continuous decline of farmland

[5] In China, economic activities are categorized into the following three strata of industry: primary industry refers to agriculture, forestry, animal husbandry and fishery and services in support of these industries; secondary industry refers to mining and quarrying, manufacturing, production and supply of electricity, water and gas, and construction; tertiary industry refers to all other economic activities not included in the primary or secondary industries (NBSC, 2007).

Table 1
Explanation of pattern measures

Pattern measure	Definition	Explanation
Maximum patch area		units = ha
Minimum patch area		units = ha
Mean patch size	$\frac{CA_i}{n_i}$	CA_i, total class area of land use i; n_i, total number of patches in land use i; units, ha
Patch density	$\frac{n_i}{A}$	A, total landscape area; units, 1/km^2
Landscape shape index	$\frac{e_i}{\min e_i}$	e_i, total length of edge (or perimeter) of class i in terms of number of cell surfaces; min e_i, minimum total length of edge of class i in terms of number of cell surfaces; ≥1, without limit
Patch cohesion index	$\left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} 100$	p_{ij}, perimeter of patch ij in terms of number of cell surfaces; a_{ij}, area of patch ij in terms of number of cells; A, total number of cells in the landscape; varies between 0 and 100
Aggregation index	$\left[\frac{g_{ii}}{\max - g_{ii}}\right] 100$	g_{ii}, number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method; max-g_{ii}, maximum number of like adjacencies (joins) between pixels of patch type (class) i based on the single-count method; varies between 0 and 100

(Long et al., 2007a). Moreover, due to loose and neglected protection of the environment, the consequences of uncontrolled rural industrialization in this region are particularly serious (Xie et al., 2007a). Rapid loss of farmland and ongoing deterioration of local environment are major concerns in Su–Xi–Chang region, which should take the lead in China in achieving the objectives of building a new countryside.

Materials and methods

Data source and processing

The vector data of land-use and land-cover change was obtained through detection analysis of historical Landsat TM (Thematic Mapper) satellite images in 1990, 1995, 2000 and 2006, from the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences and China National Environmental Monitoring Center. An efficient classification system was drafted and an effective research team was organized to work on remote sensed data through human–machine interactive interpretation to guarantee classification consistency and accuracy (Liu et al., 2005b). Based on these Landsat TM data, four land-use maps in 1990, 1995, 2000 and 2006 were classified into 10 LULC types: paddy fields, dryland, forested land, grassland, natural lakes and rivers, artificial ponds, urban settlements, rural settlements, unused land, and construction land mainly for industry, mining and transportation. Then, we measured the variations among the ten different LULC types by converting the four LULC vector format maps into raster format with a spatial resolution of 100 m × 100 m using ESRI's ArcGIS spatial analyst module. In addition, some time-series socio-economic data on land use and industry from 1990 to 2006 (JSB, 1991–2007), were collected from the local governments and used to analyze potential driving forces resulting in land-use change in study area.

Methods

The four gridded LULC maps were mainly used to detect the internal variations of LULC in Su–Xi–Chang region between three different periods: from 1990 to 1995, from 1995 to 2000, and from 2000 to 2006. For each pair of gridded datasets, a change matrix was constructed. Then, for each LULC category i in a change matrix A, the change between the three periods was calculated according to the following Eq. (1), and for each LULC type we calculated the percentage of "conversion loss to" or "conversion gain from," in relation to the total "loss or gain" conversion of a LULC type according to Eq. (2) (Long et al., 2007b).

$$\mathrm{CH}_i = \frac{p_{i.} - p_{.i}}{p_{.i}} \times 100 \tag{1}$$

where CH_i is the change of LULC in row i relative to the previous compared year; $p_{i.}$ is the row total of grid cells for category i; $p_{.i}$ is the column total of grid cells for category i.

$$\begin{cases} P_{\mathrm{loss}(i),j} = \dfrac{p_{j,i} - p_{i,j}}{p_{i.} - p_{.i}} \times 100, & i \neq j \\ P_{\mathrm{gain}(i),j} = \dfrac{p_{i,j} - p_{j,i}}{p_{i.} - p_{.i}} \times 100, & i \neq j \end{cases} \tag{2}$$

where $P_{\mathrm{loss}(i),j}$ is the percentage taken by type j in the total "conversion loss" of category row i; $P_{\mathrm{gain}(i),j}$ is the percentage taken by type j in the total "conversion gain" of category row i; $p_{i,j}$ and $p_{j,i}$ is the individual entry in a change matrix A.

To examine the spatial patterns of farmland (including paddy fields and dryland) and rural settlements and their change over time, we identify a set of pattern metrics that capture different

Table 2
Change matrix of each compared LULC type in 1990 and 1995, and its changes in 1995 (ha)

LULC type in 1995	LULC type in 1990											Changes in 1995 (%)
	PF	DL	FL	GL	LR	AP	US	RS	CL	UL	Total	
PF	908 085	5			16	622	7	16			908 751	−6.14
DL	3	95 152	1				1	1			95 158	−16.52
FL		1	96 611				1	1			96 614	−0.19
GL				4229							4 229	−0.09
LR	680				359 542						360 222	0.18
AP	6 026	146	2			87 198					93 372	6.29
US	23 078	15 433	13		0	5	50 375	56	42		89 002	76.65
RS	28 763	3 130	124	4	0	21	0	77 460			109 502	41.23
CL	1 555	123	43						3147		4 868	52.65
UL	8									682	690	1.17
Total	968 198	113 990	96 794	4233	359 558	87 846	50 384	77 534	3189	682	1 762 408	

Note: PF, paddy fields; DL, dryland; FL, forested land; GL, grassland; LR, natural lakes and rivers; AP, artificial ponds; US, urban settlements; RS, rural settlements; CL, construction land; UL, unused land.

Table 3
Change matrix of each compared LULC type in 1995 and 2000, and its changes in 2000 (ha)

LULC type in 2000	LULC type in 1995											Changes in 2000 (%)
	PF	DL	FL	GL	LR	AP	US	RS	CL	UL	Total	
PF	881 290	357	30		4	29	4	10			88 1724	−2.97
DL	80	91 569	123			37	1				91 810	−3.52
FL	64	117	94 210					23			94 414	−2.28
GL	10		11	4 103	177						4301	1.70
LR	1				359 257						359 258	−0.27
AP	3 372	193	161	15	624	92 941		10			97 316	4.22
US	9 028	875	188	21	16	144	88 992				99 264	11.53
RS	13 436	1 423	997	49	49	211	5	109 459			125 629	14.73
CL	1 470	624	852	41	95	10			4868		7 960	63.52
UL			42							690	732	6.09
Total	908 751	95 158	96 614	4 229	360 222	93 372	89 002	109 502	4868	690	1 762 408	

Note: PF, paddy fields; DL, dryland; FL, forested land; GL, grassland; LR, natural lakes and rivers; AP, artificial ponds; US, urban settlements; RS, rural settlements; CL, construction land; UL, unused land.

dimensions of land fragmentation (Table 1): (i) maximum patch area, (ii) minimum patch area, (iii) mean patch size, (iv) patch density, (v) landscape shape index, (vi) patch cohesion index, and (vii) aggregation index, which are calculated using FRAGSTATS, a spatial pattern analysis program for categorical maps (McGarigal et al., 2002). Considering the limitation of only 4 years of LULC data (derived from remotely sensed images), we used the annual series of farmland data to explore the possible driving forces contributing to land-use change in study area. *R* (R Development Core Team, 2006), a language and environment for statistical computing, is used to explore the correlations between different socio-economic variables.

Results

Land-use change in Su–Xi–Chang region

Land use has changed significantly over the whole period from 1990 to 2006 in Su–Xi–Chang region (Tables 2–4). During the three periods of from 1990 to 1995, from 1995 to 2000, and from 2000 to 2006, paddy fields and dryland decreased by 6.14% and 16.52%, 2.79% and 3.52%, and 7.96% and 3.99%, respectively. In contrast, urban settlements, rural settlements and construction land increased by 76.65%, 41.23% and 52.65%, respectively, from 1990 to 1995. These trends continued in the periods of from 1995 to 2000 and from 2000 to 2006. From 1990 to 1995 and from 1995 to 2000, artificial ponds expanded by 6.29% and 4.22%, respectively; however, it shrunk a little (by 1%) over the period between 2000 and 2006. The change trends of forested land, grassland, natural lakes and rivers, and unused land are not obvious over the whole period between 1990 and 2006, except for an increase of about 23.5% for grassland and unused land from 2000 to 2006 (Table 4). To a large extent, land-use change from 1990 to 2006 in Su–Xi–Chang region was characterized by a serious replacement of farmland with urban and rural settlements, construction land, and artificial ponds.

Dynamic patterns and driving forces of farmland change

Fragmentation is the obvious characteristics of paddy fields change in the study area (Fig. 2), and we find substantial and significant increases in mean fragmentation values of paddy fields over the whole period from 1990 to 2006 in Su–Xi–Chang region (Table 5). In 1990, the mean patch size of paddy fields was 1204.4 ha, and by 2006 the size was only 138.8 ha. The patch density of paddy fields increased by 331.5%, and it changed from 0.033 in 1990 to 0.144 in 2006. From 1990 to 2006, the fragmentation of paddy fields can also be proved by the continuous decline of aggregation index and rapid increase of landscape shape index (Table 5). Nevertheless, the most interesting result we find is the decreases in mean fragmentation values of dryland from 1990 to 2006 in the study area, as evidenced by the values change of mean patch size, patch density, aggregation index and landscape shape index (Table 5).

The accelerating industrialization and urbanization process may increase the degree of fragmentation and structural complexity of LULC. Our statistical analysis also suggested that population growth, rapid industrialization and urbanization are the major driving forces of farmland change in Su–Xi–Chang region from 1990 to 2006 (Fig. 3).

Table 4
Change matrix of each compared LULC type in 2000 and 2006, and its changes in 2006 (ha)

LULC type in 2006	LULC type in 2000											Changes in 2006 (%)
	PF	DL	FL	GL	LR	AP	US	RS	CL	UL	Total	
PF	801 132	32	472		581	3 638	2 086	3 158	48	413	811 560	−7.96
DL	106	85 665	517		30	302	396	1 122		5	88 143	−3.99
FL	1 909		91 304	83	560	1 137	17	108		23	95 141	0.77
GL	370			3 993	740	49	105	52		6	5 315	23.58
LR	282	76	65		351 487	250	3				352 163	−1.97
AP	4 478	31	123	15	3 615	87 334	40	669	6	35	96 346	−1.00
US	34 632	1 821	270	29	232	617	96 615	3 965		200	138 381	39.41
RS	35 186	1 408	777	17	1 508	3 299		116 361		19	158 575	26.22
CL	3 419	2 777	240	164	492	689	2	161	7 906	31	15 881	99.51
UL	210		646		13	1		33			903	23.36
Total	881 724	91 810	94 414	4 301	359 258	97 316	99 264	125 629	7 960	732	1 762 408	

Note: PF, paddy fields; DL, dryland; FL, forested land; GL, grassland; LR, natural lakes and rivers; AP, artificial ponds; US, urban settlements; RS, rural settlements; CL, construction land; UL, unused land.

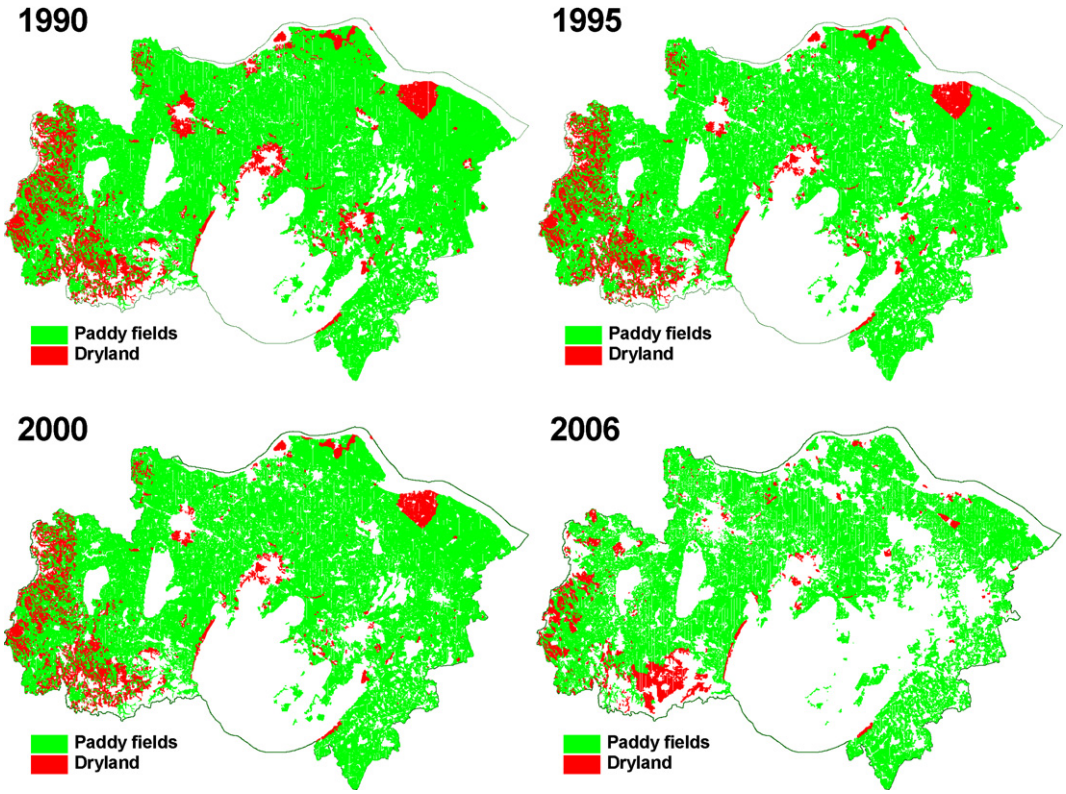

Fig. 2. Change pattern of farmland in Su–Xi–Chang region.

Rapid industrialization and urbanization in Su–Xi–Chang region is a very significant factor of land-use change, which can be illustrated by the strong negative relationship between farmland and total industrial output value (Fig. 3a), and between farmland and population (Fig. 3b). In addition, industrialization and urbanization have apparently triggered massive farmland loss for the benefits of market-oriented farming and non-agricultural development (Long et al., 2007b). According to Fig. 3c, there was a strong negative relationship between farmland and aquatic products.

Table 6 presents the land-use change resulted from industrialization and urbanization. Urban settlements expansion accounted for 38.81%, 33.39% and 46.39% of the decrease of paddy fields, and for 81.95%, 26.11% and 38.86% of the decrease of dryland, during the periods of from 1990 to 1995, from 1995 to 2000 and from 2000 to 2006, respectively. Similarly, the expansion of rural settlements occurred mainly at the expense of paddy fields and dryland, which accounted for 48.36%, 49.68% and 45.65% of the changes in paddy fields, and for 16.62%, 42.5% and 7.8% of the decrease of dryland, during the periods of from 1990 to 1995, from 1995 to 2000 and from 2000 to 2006, respectively. During the period between 2000 and 2006, the expansion of construction land accounted for 75.73% of the decrease of dryland. The expansion of artificial ponds occurred mainly at the expense of paddy fields, which accounted for 9.09% and 12.37% of the changes in paddy fields during the periods of from 1990 to 1995 and from 1995 to 2000, respectively. In addition, the decreases in mean fragmentation values of dryland may be due to the demands for developing modern agriculture and the scale management of agriculture.

Dynamic patterns and driving forces of rural settlements change

From 1990 to 2006, rural settlements change in Su–Xi–Chang region has a dual characteristic of coexisting fragmentation and aggregation (Fig. 4), as evidenced by the changes of mean fragmentation values of rural settlements over the whole period from 1990 to 2006 (Table 5). On the one hand, the fragmentation of rural settlements can be proved by the continuous increase of landscape shape index and patch density from 1990 to 2006 (Table 5). On the other hand, during the same periods, the maximum patch area is continuously increased double or more, and the value of patch cohesion index has been keeping on increasing

Table 5
Aggregate land-use pattern measures

Pattern measure	Paddy fields				Dryland				Rural settlements			
	1990	1995	2000	2006	1990	1995	2000	2006	1990	1995	2000	2006
Maximum patch area	87 847	82 960	77 509	86 193	15 475	13 875	13 430	15 252	142	369	504	1261
Minimum patch area	0.020	0.017	0.014	0.005	0.009	0.021	0.021	0.005	0.010	0.011	0.011	0.007
Mean patch size	1204.4	1409.3	1017.2	138.8	75.2	85.7	76.0	112.4	8.4	12.0	11.4	12.1
Patch density	0.033	0.029	0.042	0.144	0.075	0.057	0.062	0.029	0.511	0.499	0.585	0.646
Landscape shape index	76.7	85.8	92.6	137.6	68.1	64.9	66.1	39.0	123.5	125.3	134.7	153.4
Patch cohesion index	99.96	99.95	99.95	99.78	97.19	97.38	97.36	96.93	71.56	76.98	78.42	87.61
Aggregation index	92.30	91.09	90.23	82.44	80.05	79.22	78.41	83.49	55.85	62.31	62.17	60.22

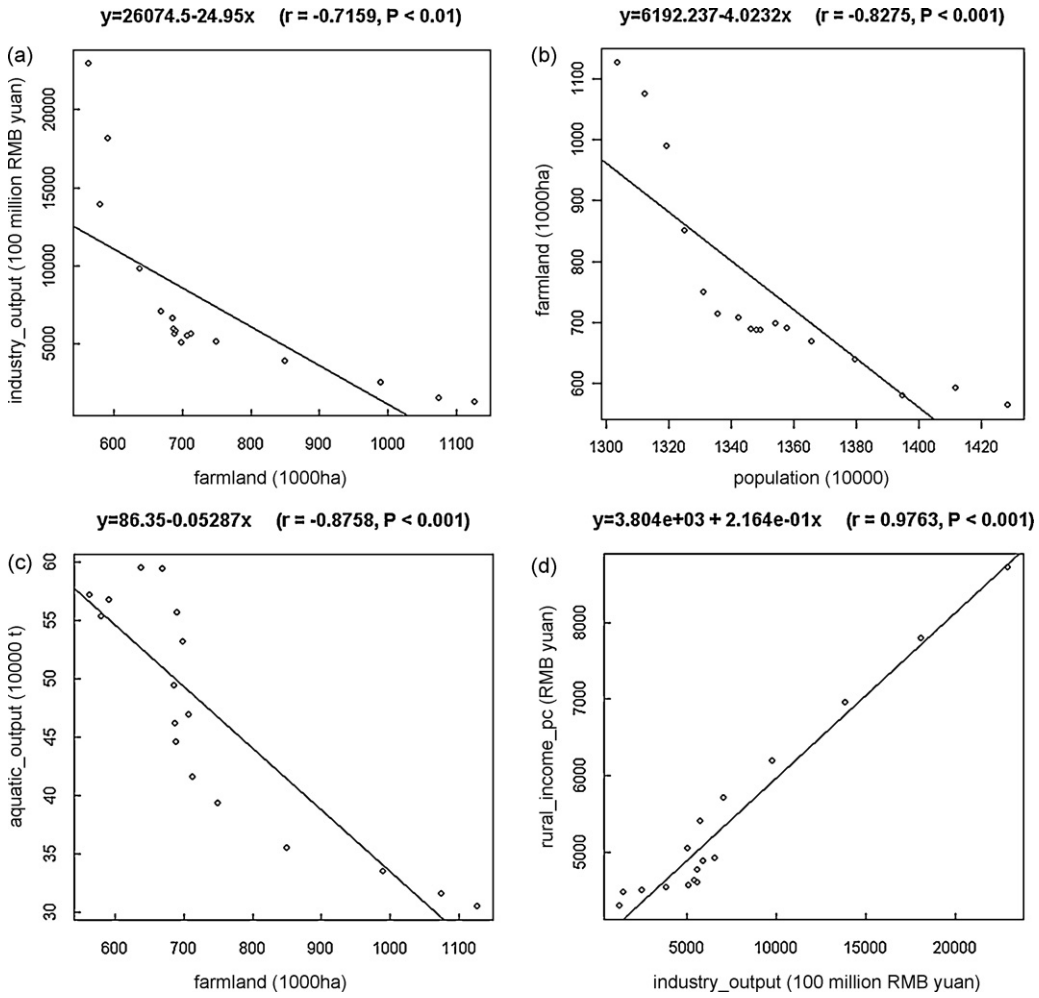

Fig. 3. The correlationship of farmland vs. industrial output value (a), farmland vs. population (b), farmland vs. aquatic products (c), and industrial output value vs. net income per capita of rural households (d) of Su-Xi-Chang region between 1990 and 2006.

(Table 5). *Patch cohesion index* measures the physical connectedness of the corresponding patch type. Below the percolation threshold, patch cohesion is sensitive to the aggregation of the focal class. Patch cohesion increases as the patch type becomes more clumped or aggregated in its distribution; hence, more physically connected (Gustafson, 1998). The expansion of rural settlements occurred mainly at the expense of farmland, as evidenced by more than 92% of the increased rural settlements are from farmland (Table 6).

The China's economic reforms played an important role in the transformation of rural settlements. The implementation of the responsibility system has aroused Chinese peasant's enthusiasm, liberated Chinese countryside from the self-sufficient status to open up a new prospect with the emerging of TVEs. China's TVEs are widely regarded as the primary form of rural industrialization (Shen and Ma, 2005). As Lin and Ho (2003) pointed out, the expansion of construction land is largely a result of rural industrialization in China. Numerous factory buildings can be easily seen in the res-

Table 6
The percentages taken by corresponding types in internal conversions of PF, DL and RS (%)

LULC type	PF^-			DL^-			RS^+		
	1990–1995	1995–2000	2000–2006	1990–1995	1995–2000	2000–2006	1990–1995	1995–2000	2000–2006
PF				0.01	8.27	−2.02	89.92	83.25	97.21
DL	0.00	−1.02	0.11				9.79	8.82	0.87
FL		0.13	2.05		−0.18	−14.10	0.38	6.04	2.03
GL		0.04	0.53				0.01	0.30	−0.11
LR	1.12	−0.01	−0.43			1.25		0.30	4.58
AP	9.09	12.37	1.20	0.78	4.66	−7.39	0.07	1.25	7.98
US	38.81	33.39	46.39	81.95	26.11	38.86	−0.18	0.03	−12.03
RS	48.36	49.68	45.65	16.62	42.50	7.80			
CL	2.62	5.44	4.80	0.65	18.64	75.73			−0.49
UL	0.01		−0.29			−0.14			−0.04

Note: PF, paddy fields; DL, dryland; FL, forested land; GL, grassland; LR, natural lakes and rivers; AP, artificial ponds; US, urban settlements; RS, rural settlements; CL, construction land; UL, unused land; $^-$, conversion loss to; $^+$, conversion gain from.

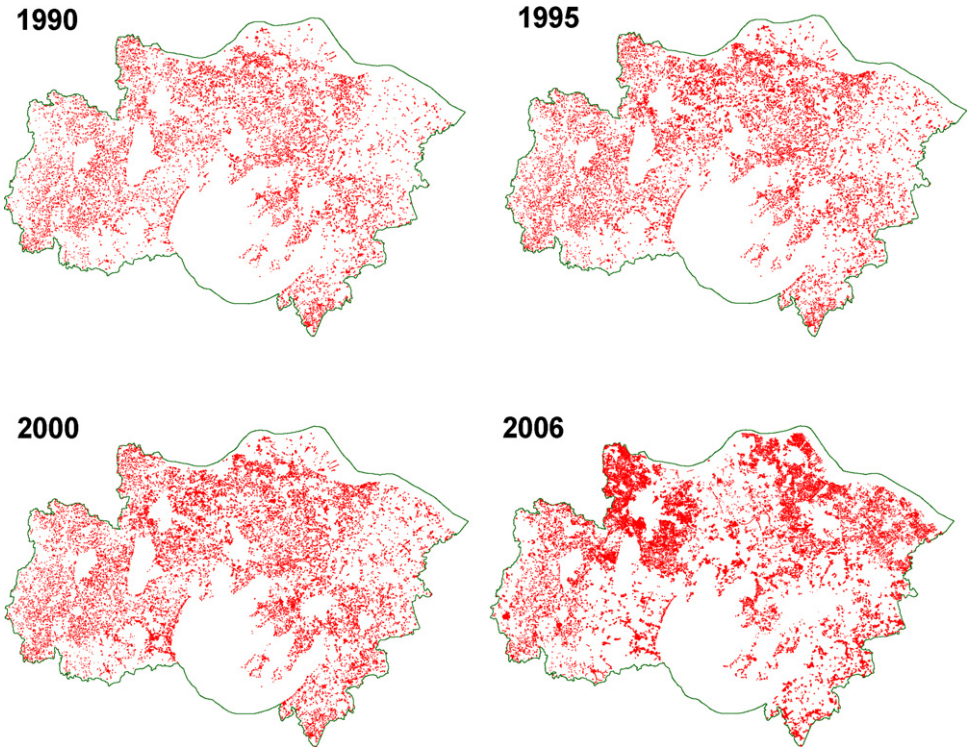

Fig. 4. Change pattern of rural settlements in Su–Xi–Chang region.

idential backyards of the villagers in coastal China (Shen and Ma, 2005). In addition, rural industrialization contributes significantly to the increase in rural income levels and employment by making full use of the local resources, utilizing the capital scattered in the peasant's hands, developing the wisdom of the skilled craftsmen, and rising up the peasant's income, which can be illustrated by the very strong positive relationship between industrial output value and net income per capita of rural households (Fig. 3d).

Usually, peasants in China want to build another new multi-functional, more comfortable or spacious house if they become affluent, although present housing can fundamentally meet their needs. Farmers prefer to build their houses close to roads and other available infrastructure. The houses usually have small-scale household (in which only three persons or so live) and larger courtyards. There is a short cycle of replacing old house with a new one. As a result, there is more idle rural housing land, vacant rural housing, with unoccupied land in villages. That can explain the fact of the expansion of rural settlements (Tables 2–4), although there was a decline trend in rural population and the number of rural households, which decreased 214 thousand, from 2945 thousand in 2000 to 2731 thousand in 2006 (JSB, 2001, 2007). Over the period from 2000 to 2006, we can find an obvious transformation from rural settlements to paddy fields and dryland, which amounted to 4280 ha (Table 4). However, from 1990 to 2000, only 27 ha rural settlements was changed to farmland (Tables 2 and 3). That is mainly due to the new policies of building a new countryside and carrying out rural construction land consolidation.

Discussion and conclusions

The rapid industrialization and urbanization in coastal China increased the demand for non-agricultural land, which diminished farmland and withered the traditional agriculture. The industrialization pushed forward the development of TVEs, which led the expansion of rural settlements and the pollution of local environment. Hence, the focuses of building a new countryside in coastal China need to be concentrated on protecting the farmland, developing modern agriculture, and building "clean and tidy villages."

In coastal China with rapid urbanization and industrialization, local further development needs land, which is very scarce. However, local government grasped the opportunity of an innovative land management policy called "linking up increased urban construction land with decreased rural construction land".[6] Land displacement and centralized settle-down is a principal model, also a successful model that local governments thought, of building new countryside in coastal China.

Usually, the model is operated in this way: at first, village collectives jointly with some enterprises with strong economic base invest to construct a brand-new community (Fig. 5); then, try to persuade the peasants to give up their farmland and rural housing land and move into the new community by promising to provide new apartments (or subsidies) and employment in the enterprises for those who moved in, thus the peasants can live the 'city life'. In most cases, peasants submitted to the village collectives (or local governments) driven by immediate interests, and gave up their land. The village collective put together the let farmland and subleased them to some plant companies or individuals who want to manage a lot of land; in return, the peasants who found a job in enterprise and gave up their land could get limited money for their land shares. Much 'new' land is displaced out by carrying out rural settle-

[6] The policy "linking up increased urban construction land with decreased rural construction land" means that, in a county level, the increased construction land for future urban development should be no more than the decreased rural construction land, which will be turned into cultivated land through carrying out rural construction land consolidation, so as to keep the total construction land in this county not to increase, to keep the quantity and quality of local farmland not to decrease, and to form a rational land-use patterns. The actual potential of existing rural construction land in a county needs to be investigated and corresponding plan for carrying out rural construction land should be laid out before implementing this policy.

Fig. 5. A new rural community in Kunshan city of Su–Xi–Chang region. (Photo taken by the first author.)

ments consolidation. However, most are allocated as construction land instead of returning to arable land according to the innovative land management policy. The enterprises who invested for building new community get enough land for expanding their production scale. The village collective builds some standard rental factory workshops on the 'new land', and promised that the rent will be used for the expenditure of village public affairs and capital bonus assigned to villagers. To great extent, this kind of model contributed to the aggregation of rural settlements from 2000 to 2006 (Fig. 4 and Table 5).

This model of building new countryside in coastal China brought about obvious land-use change, and the impacts of which on the livelihood of rural residents were far-reaching. Although the farmland per capita was declined from 0.052 ha in 2000 to 0.04 ha in 2006, the livelihood of rural residents is improved greatly. Guohao Liu, the village head of Taixing village in Shaxi town of Taicang city in the northeast of Su–Xi–Chang region, told us that the increased villagers' net income per capita in 2006 from collective-owned land was 1880 RMB¥, which was composed of 560 RMB¥ capital bonus of collective assets, 900 RMB¥ rent of farmland subleased to Ltd. Company of Suzhou Urban Greenbelt, and 420 RMB¥ laborage for working at the Company.

However, in general, there are some latent problems in the back of the so-called successful model. To some extent, the village and township governments are selling off land to developers in a disguised form just to feed their staff, because township and village governments are paralyzed from lack of funding since the central government's decision 2 years ago to abolish the agricultural tax, although it can bring some help for village public affairs. But they did not care of the peasants' future livelihoods. First of all, those peasants who lack of special skills and are employed in the enterprises will confront the situation of unemployment to a great extent, because most of the enterprises what they are working at are labor-intensive industries, which are experiencing the phase of industrial upgrade. At present, lots of polluted, labor-intensive industries in eastern/coastal China are being gradually transferred to central region and western region. But the pace of peasants' skill improvement cannot chase up that of industrial upgrade, which may cause their unemployment in the near future. In addition, the enterprises, in order to save more land for their industrial development, try to build high-rise apartment buildings (some even with 35 floors) without considering the carrying capacity of local resources and environment, which brings a lot of inconvenience for the new dwellers. Cultural landscape should not be overlooked in land consolidation (Cai, 2004). Lacking of original rural landscape and rural culture, some interviewed older peasants, who have moved into the new apartments, usually miss the life living in their old houses, which were already not existed.

Rural construction land consolidation may play an important role in protecting the farmland and building "clean and tidy villages." First, farmland may be increased or 'new' construction land may be available for meeting the needs of future economic development, which can also reduce the conversion of farmland in the future. Second, consolidating rural construction land accompanied with the campaign of building new countryside is an effective prescription of changing the appearance of "dirty, disorderly and bad" in rural China. Finally, it can improve the villagers' living conditions. Accordingly, consolidating rural construction land needs to be carried out by the following ways: (1) local governments should first register idle rural housing land, vacant rural housing, idle workshop of insolvent TVEs, unoccupied land in villages, and cases where one household owns two or more houses according to local conditions, so as to estimate the actual potential of existing construction land, then set down and implement rational plans of consolidating rural construction land according to the general land-use planning and local developing strategy, in order to enhance the intensity of land use in town and village and save land for further needs; (2) putting together the dispersed rural housing (needs to be improved) and TVEs to establish new residential areas and new industrial areas with unified planning and design and perfect infrastructure (roads, water, electricity, sewage, gas, heating and telecommunications), for the purpose of improving villagers' living conditions and building a clean and tidy village. From 2000 to 2006 rural settlements consolidation contributed to the increase of 4280 ha farmland (Table 4). However, it should be clear that rural construction land consolidation will confront many obstacles. For example, most peasants have strong reminiscent mood and are not willing to move to live in another area; China's land legal and managerial system is somewhat problematic involving rural housing land consolidation in the aspect of land-use rights (Ding, 2007); and the benefit allocation system of stakeholders concerning rural construction land consolidation needs to be established, which cannot come to an agreement in a short time.

The study of Li and Wang (2003) showed that the low incentive for raising agricultural land-use intensity may more seriously threaten food security than the shrinking cultivated land area or the low technological potential in China. At present, China's farmers have seldom interest in pursuing grain production, largely because it generates very low net income,[7] which resulted in millions of farmers being out of countryside and the continuous decline of the percentage of primary industry in the GDP of the Su–Xi–Chang region, from 15.35% in 1990 to 2.11% in 2006 (Fig. 6). On the contrary, it creates some opportunities for developing modern agriculture and the scale management of agriculture. During the period between 2000 and 2006, many modern agricultural gardens were established. Through carrying out cultivated land consolidation, the maximum patch area of paddy fields and dryland in study area increased from 77 509 ha and 13 430 ha in 2000 to 86 193 ha and 15 252 ha in 2006, respectively (Table 5).

[7] Our household interview in a village of coastal China showed that a farmer can only obtain profit of 580 RMB¥, which still includes his man-days pay, from planting 1 mu (1 mu = 0.067 ha) rice: the annual yield is 600 kg, the price is 1.48 RMB¥ per kg, and the total income from planting rice is 888 RMB¥; however, the total expenditure is 308 RMB¥, which includes 100 RMB¥ for fertilizer, 160 RMB¥ for pesticide, and 48 RMB¥ for plowing land. But he can earn 40 RMB¥ per day if he pursues other labor activities on building site.

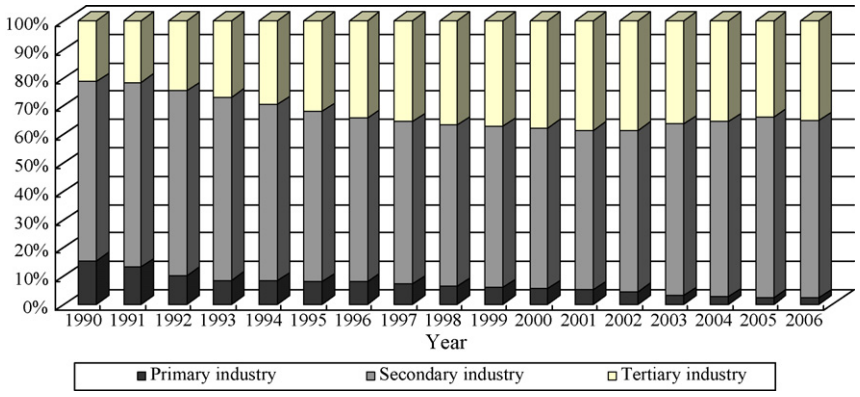

Fig. 6. Change in industrial structure of Su–Xi–Chang region between 1990 and 2006.

Frankly, cultivated land consolidation may contribute to developing modern agriculture and strengthening the productive forces of the countryside in the following aspects: (1) to enhance land productivity and labor productivity through improving land quality, irrigation conditions and machinery accessibility; (2) to reduce land fragmentation and improve the efficiency of agricultural production; (3) to form rational, efficient and intensive land-use structure by reallocating land resources; (4) to facilitate adjustments to the crop structure through general improvements in land conditions; and (5) to promote the progress of agricultural industrialization and scale management of agriculture.

To achieve coordinated and balanced development between urban and rural areas in Su–Xi–Chang region, it can be seen from the dynamic patterns of farmland and rural settlements in Figs. 1, 2 and 4 that an urban–rural integrated development planning is necessary. Urban sprawl is increasingly considered a significant and growing problem that entails a wide range of social and environmental costs (Bengston et al., 2004). China's rural area used to pay the bill for these costs due to lacking early planning. When some loads resulting from urban expansion were shifted upon rural area, the rural had no choice but to take over the heavy burden, although without any preparation. It is fundamental to lay out a scientific plan for building a new countryside, and the plan should coincide with local land-use planning, urban planning and land consolidation planning. Hence, for the long run, the plan for building new countryside needs to pay more attention to making the rural have certain functions serving for the urban, e.g. accepting some transferred industries, providing ecological and other kinds of services for urban population. In addition, we need to reserve and respect the cultural elements of idyll and the rural landscape, in the process of building a new countryside in coastal China, instead of building a new countryside, which looks more like a city.

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