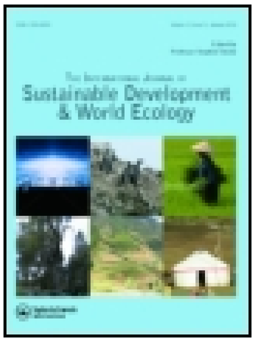

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Ecological effects associated with land-use change in China's southwest agricultural landscape

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Key words: Land-use change, ecological effects, agricultural landscape, Yongsheng County, southwest China

SUMMARY

Research on land-use and land-cover change, with associated effects on the eco-environment, is a key to understanding global change. The concept of 'ecosystem services' is also a hot issue in ecology and ecological economics. In this study, ecosystem service values are used to assess the ecological values of corresponding land-use types, so as to evaluate the ecological effects of regional land-use change. China's southwest agricultural landscape has unique ecological functions; but it also belongs to an ecologically fragile zone. Consequently, land-use change and associated ecological effects must be monitored to assure sustainable development of this area. Based on TM images in 1988, 1994 and 1999, the landscape classification maps of Yongsheng County were assessed using supervised classification and interactive modification methods. The transition matrix of land-use types and three indices of spatial patterns, patch-level, class-level and landscape-level indices, were calculated using models and GIS to examine the spatial patterns and dynamics of land use in the study area. The results show the influences of human activities and natural environmental elements, and that unused land has decreased rapidly, together with a continuous increase in forest during the past 11 years. There are also frequent intermediate transitions between farmland and unused land. An index for landscape diversity shows a tendency to increase, indicating that the proportions of each landscape element tended to average. Also, the decrease in the fractal dimension of unused land reveals that the effects of human activity are increasing. Ecological value calculations show that land-use change in Yongsheng County from 1988–1999 has resulted in positive ecological effects, with distinct spatial differences.

INTRODUCTION

Land-use/land-cover change (LUCC) is an important component and the main cause of global environmental change (Chen *et al*. 2003). It is also the focus of advanced research on sustainable development (Liu and Chen 2002), and the future of human beings. Since the IGBP and IHDP presented the LUCC plan, this topic has rapidly attracted more attention. Together with increasing

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interest in LUCC, scholars not only pay attention to the classification of land-use and land-cover types, analysis and evaluation of LUCC in typical regions, dynamic monitoring of LUCC through RS and GIS, and LUCC modelling at global or regional scales, but also emphasize the eco-environmental effects of land-quality change and eco-environmental security patterns.

LUCC not only results in changes to the landscape structure of the Earth's surface, but also influences material cycles and energy flow in the landscape, and biodiversity and important ecological processes in a region. It is therefore meaningful to study the relationship between the LUCC and the eco-environment to understand potential regional eco-environmental change. It would be a great help to maintain ecological balance and promote harmonious development of both the regional economy and the environment. Although existing research places more attention on global influences and responses of LUCC, and especially to influences on climate change and trace gases (Turner 1997; Dale 1997), it pays insufficient attention to regional ecological processes. Thus, analysis and evaluation of eco-environmental effects of LUCC for some typical regions, and especially the influences of the important ecological processes, have become a major field in LUCC research.

Pattern and process are the core contents of landscape ecology (Wang 1998). The study of the eco-environmental effects of LUCC is also part of this field. LUCC research emphasizes quantitative analysis of the landscape pattern; while research into eco-environmental effects emphasizes functional change in landscape ecosystems, which are a part of the landscape process. Landscape metrics, such as diversity, fragmentation and contagion, in the analysis of landscape pattern can partly represent changing ecological fragmentation, edge effects and other landscape functions, in terms of spatial patterns. The analysis and evaluation of eco-environmental effects of LUCC embraces three aspects: (1) single factor analysis of LUCC on the regional climate, soil, hydrology and other eco-environmental elements; (2) building a system of evaluation indices to evaluate the general eco-environmental effects of LUCC; and (3) analysis of the ecological meaning of landscape metrics so as to evaluate eco-environmental effects of spatial patterns and thus understand mutual influence mechanisms between landscape patterns and ecological processes.

It is unfortunate that most of existing LUCC research focuses on a qualitative approach and single factor analysis of environmental elements, for example influences on regional climate (Stohlgren *et al.*, 1998; Kornelia and Judit, 2002), hydrology and water resources (Deng 2001; Shi *et al.* 2001), soil quality and soil erosion (Fu *et al.* 1994; Sommer *et al.* 1998; Islam and Weil 2000), and biodiversity (Jorg and Steffen 2003; Thomas *et al.* 2004). A literature search reveals few attempts at integrated quantitative analysis and evaluation of the ecological effects of LUCC, especially on influences mechanism analysis of important ecological processes.

The concept of 'ecosystem service' is one of the most important and advanced fields in ecology and eco-economy research at present. Since the concept of global ecosystem services was suggested by Costanza and colleagues (1997), it has become widely accepted and used. Ecosystem services constitute the natural condition and efficiency for human survival in the development of ecosystems and ecological processes. Costanza *et al.* (1997) calculated the mean economic value of the ecosystem service for 16 kinds of land-use and land-cover types. Thus, we can assess the ecological quality of regional land-use types according to the proportional relationship of the ecosystem service, and then evaluate the ecological value change due to LUCC.

China's southwest agricultural landscape comprises a transitional region between the Qinghai-Tibet Plateau and the Yunnan-Guizhou Plateau and has unique ecological functions. This area is extremely rugged with snowy mountains and deep gorges. It also belongs to an ecologically fragile zone, with the characteristics of a fluctuating regional eco-environment, instability, weak adjustment of the ecosystem and sensitivity to exterior disturbance. The significantly changing land use and land cover will influence the structure and function of landscape ecosystems and result in profound changes to the regional eco-environment, particularly in an ecologically fragile zone. Consequently, such an ecologically fragile zone is the best case study area for research on global LUCC and its ecological effects, with profound meaning for regional responses to global environment change. Currently, a few scientists have studied LUCC in ecologically fragile zones (Lv *et al.* 2001; Huang *et al.* 2002), but all so far lack research on the ecological effects of LUCC.

Yongsheng County in northwest Yunnan Province was chosen as the study area to analyze the characteristics of regional land-use change and associated ecological effects from 1988 to 1999. The objectives of this study were to: (1) identify land-use change processes in China's southwest agricultural landscape within the past 11 years through analysis of the dynamics of landscape metrics; and (2) consider relative changes from the global mean economic value of the ecosystem service in order to evaluate the ecological effects of LUCC.

MATERIALS AND METHODS

Study area

The study area, Yongsheng County in NW Yunnan Province (100°22′–101°11′E and 25°59′–27°04′N) is adjacent to Huaping to the east, Binchuan to the south, Lijiang and Heqing to the west and Ninglang to the north, with the Yangtze River flowing through the county (Figure 1). The distances from east to west and from south to north are 82 km and 140 km, respectively, and the altitude decreases from north to south. The total land area is 4950 km^2, 92.42% of this area being mountainous. Yongsheng County has a low latitude and plateau monsoonal climate with four seasons clearly demarcated: dry in winter and spring and wet in summer and autumn.

As Yongsheng County is located in the transition zone extending from the low altitude of the Yunnan Plateau to the high altitude of the Qinghai-Tibet Plateau, the land is quite poor, with rugged terrain, thin soils, heavy water and soil erosion, low mean annual precipitation (about 1000 mm), low mean annual temperature (7.9–10.5°C), and a deficiency in light and heat resources. Therefore, the eco-environment in Yongsheng County is fragile.

Agriculture in Yongsheng County has a long history, but secondary and tertiary industry both lack development. Until the end of 1999, the population of the whole county was 375,133, including 93.5% agricultural population and 30.46% minority population (mainly Hui and Yi). There are 18 towns in Yongsheng County, Yongbei, Jinguan, Liangguan, Qina, Renhe, Chenghai, Taoyuan, Pianjiao, Taiji, Shunzhou, Banqiao, Songping, Guanghua, Liude, Dongshan, Yangping, Daan and

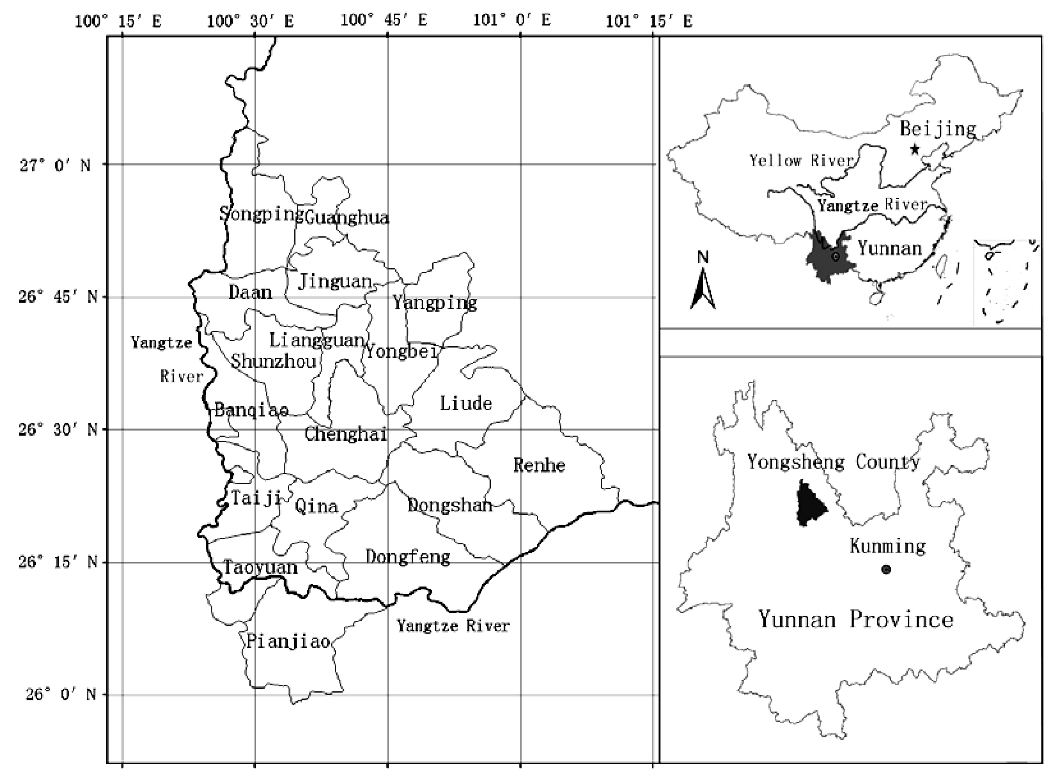

Figure 1 Map of the study area in Yongsheng County, Yunnan Province

Dongfeng, and these have a total of 147 administrative villages and 1375 natural villages.

Land-use database

Data on changes in land use in the study area can be obtained by analyzing remote sensing images from 1988, 1994 and 1999. According to the land-use maps of Yongsheng County in 1993 and 2000 (scale 1:75 000), the relief map of Yongsheng County (scale 1:500 000), and social and economic information obtained by fieldwork and from the local statistical yearbook, this study has revised some land-use types in parts of the region.

To meet requirements of the analysis of the ecological effects of the land-use change, based on ecosystem types, we classified land use into 7 types, based on the present land use in Yongsheng County. These are paddy field (irrigated land situated on flat areas), dry land (without irrigation water or facilities and relying on natural precipitation), forest land (forests, shrublands, open woodland, planted areas with young forest and nurseries), harvested sites (with large herbs but not meeting the standards of open woodland, harvested forest, slash disposal sites and burned harvested sites), water bodies (rivers, lakes, reservoirs and ponds), urban land (construction land, individual industry and mining land, enterprise land, showplace and historic site land with its internal transportation and green land) and unused land (unused and land difficult to use, waste grass land, bare land, bare rock and sand dunes).

Analysis of land-use change

This study used ERDAS software, with the supervised classification and contact adjustment so as to obtain the maps of land-use types at different periods and to build the GIS database, and the FRAGSTATS software to analyze landscape metrics and the transition matrix of land-use types so as to analyze the actuality and dynamics of land-use patterns.

To reveal characteristics and dynamics of landscape patterns, one set of rational indices should include at least three aspects, i.e. shape characteristics of individual landscape patches, spatial configuration of landscape elements and diversity of the whole landscape. This study chose the landscape diversity index, contagion index, fragmentation index and modified fractal dimension index as common indices in the analysis of landscape patterns. For the calculation and ecological meanings of these landscape metrics, please refer to Fu (1995), Gustafson (1998) and Hargis *et al.* (1998).

Land-use change involves a complex mutual conversion of different land-use types. The dynamic change of landscape metrics can effectively explain the collective change characteristic of every land-use type and the whole landscape, but cannot express the detailed information of the conversion between different land-use types. Thus, we can analyze the transition matrix of land-use types for different periods, to exactly identify the process of land-use change. Based on analysis of remote sensing images, this study works through the spatial overlay of multi-temporal sets of land-use maps. That is, applying the map algebraic formula (1) which is valid when the number of land-use types is below 10, to two land-use maps (A_{I*j} and B_{I*j}) , deriving C_{I*j} , a map of land-use change from time A to time B that represents the type of land-use change and the associated spatial distribution. Through this approach, we can calculate the transition matrix of land-use types in study periods, and analyze the transition model and dynamics of land-use types in the study area.

$$C_{I*j}=A_{I*j}*10+B_{I*j} \quad (1)$$

Evaluation for ecological effects of land-use change

In this study, we evaluate the ecological quality of regional land-use types according to the proportional relation of global mean economic value of ecosystem service functions proposed by Costanza *et al.* (1997), so as to establish the correlation between land use and land cover and regional ecological quality, and to derive a quantitative evaluation of the ecological effects of LUCC in general.

As there are some differences between global mean ecosystem service functions and those for China, including low-value cultivated land and high-value wet land (Chen and Zhang 2000), we must revise the proportional relation of global mean economic value of ecosystem service functions of land-use types according to the actual conditions in the study area. The revisions are mainly due to: (1) arable land in the study area includes paddy field and dry land, and the ecosystem service functions of paddy field are higher than those of dry land; (2) ecosystem service functions of water bodies are lower than the global mean due to the simple ecosystem structure of plateau lakes and rivers; and (3) there is little urban and unused land in the study area, and this was not valued in the study of Costanza *et al.* (1997). Finally, we obtain a set of ecological values of regional land-use types (Table 1). We can calculate the total ecological value of regional land use through the weighted summation of the proportional areas of land-use types and their associated ecological values in the study area, and then evaluate ecological effects of land-use change during the study periods.

RESULTS AND DISCUSSION

Land-use change

Land-use change summary

In each study period there has been no change of land-use types in Yongsheng County, and also no change in the land-use characteristics of the agricultural landscape. But there are obvious changes in the areas of land-use types, i.e. a continual increase in urban land, forest land, harvested sites and dry land, some decrease in water bodies and paddy fields, and a rapid decrease in the area of unused land (Table 2).

During the study periods, there are few changes in the basic characteristics of the agricultural landscape in Yongsheng County, which reflects a high patch number, a small average area and average perimeter of patches. This is partly due to the natural conditions of the study area. Yongsheng County lies in an ecologically fragile zone with deep ditches and fragmented landforms. There are great differences in the landscape elements of adjacent regions, so that it is difficult to form patches with large areas.

Among all the landscape elements, the average patch area and average patch perimeter of forest land are the largest, with an increase in total area and a decrease in the number of patches. The increasingly large patches of forest land are mainly due to the transition of patches of forest land from other land-use types to forest land, resulting from artificial afforestation and forestry protection, and

Table 1 Global mean economic value of ecosystem service functions (GMEVESF) and ecological value (EV) of different land-use types in Yongsheng County

Land-use type	*Paddy field*	*Dry land*	*Forest land*	*Harvested site*	*Water body*	*Urban land*	*Unused land*
GMEVESF ($/hm^2·a)	92	92	302	232	8498	–	–
EV[a]	0.325	0.295	1.0	0.768	0.782	0.015	0.035

[a]According to Costanza *et al.* (1997), the value is adjusted to the actual condition of the study area

Table 2 Land-use change summary in Yongsheng County from 1984 to 1999

Patch characteristics		*Paddy field*	*Dry land*	*Forest land*	*Harvested site*	*Urban land*	*Water body*	*Unused land*	*Total*
Patch number	1988	35584	40607	62950	6380	3680	4584	87361	241146
	1994	43900	51114	58061	10109	6334	3914	100101	273533
	1999	51186	58649	57433	22758	7697	4284	101535	303542
Total area of patches %	1988	7.74	5.52	42.23	0.52	0.38	2.06	41.55	100
	1994	7.75	6.27	48.71	1.05	0.63	2.03	33.56	100
	1999	7.49	7.79	51.87	2.64	0.91	2.03	27.27	100
Average patch area (hm^2)	1988	1.0685	0.6681	3.2980	0.4014	0.5063	2.2132	2.3382	2.0386
	1994	0.8660	0.6028	4.1241	0.5107	0.4874	2.5523	1.6492	1.7972
	1999	0.7192	0.6531	4.4396	0.5705	0.5804	2.3347	0.0132	1.6195
Average patch perimeter (km^2)	1988	0.3628	0.3114	0.8478	0.2043	0.1952	0.7820	0.6198	0.5751
	1994	0.3043	0.2786	0.9234	0.2306	0.1806	0.9148	0.4916	0.5026
	1999	0.3186	0.2911	0.9082	0.2714	0.2151	0.8214	0.4038	0.4543

the subsequent decrease in patch number and increase of average patch area of forest land.

There are few changes in the total area of patches, an obvious increase of patch numbers, and a reduction of average patch area of paddy fields. The result shows that former paddy fields are only partly occupied, with the segmentation of paddy field in large patches by other landscape elements, and new paddy fields are cultivated in scattered small patches with appropriate natural conditions of water and heat. Meanwhile, there are notable increases in total area and numbers of patches of dry land, with few changes in average patch area and average patch perimeter. This suggests that new cultivated dry land always occurred in study periods.

Harvested sites are special landscape elements in Yongsheng County, and are mainly formed after natural forestry burning or deforestation. From 1988 to 1999, the total area of harvested sites has increased five-fold, with few changes of average patch area, which suggests that there is a tendency for the area of harvested sites to increase.

The change in urban land is mainly in the increase of total area and number of patches, and there are some changes in average patch area and average patch perimeter, which make clear the dispersive distribution pattern of newly developing patches of urban land.

The total area of water bodies has not changed, with a fluctuation of patch number and associated earlier increases and later decreases of average patch area and average patch perimeter. These suggest that the transition from water bodies to other land-use types mainly occurred in small patches, with few changes of large patches of water bodies.

With the increase of other landscape elements, the total area of unused land obviously decreased, with increasing patch number and decreasing average patch area and average patch perimeter. This suggests that, in the process of land-use change, large patches of unused land are divided into smaller patches.

The transition matrix of land-use types

From Tables 3 and 4, we can identify some important processes of land-use change:

(1) Water bodies represent a stable land-use type. The proportion of their conversion into other

Table 3 The transition matrix of land-use types in Yongsheng County from 1988 to 1994[a]

Land-use type	*Water body*	*Paddy field*	*Dry land*	*Urban land*	*Forest land*	*Harvested site*	*Unused land*
Water body	90.04	3.02	0.41	0.45	0.80	0.17	5.11
Paddy field	0.55	54.64	6.86	4.02	4.45	0.08	29.39
Dry land	0.15	10.28	30.63	0.55	13.52	0.11	44.76
Urban land	1.63	37.55	0.41	40.94	3.10	0.57	15.80
Forest land	0.04	0.26	2.21	0.01	84.59	1.25	11.64
Harvested site	0.13	3.21	10.35	0.16	48.73	7.53	29.89
Unused land	0.23	6.28	7.34	0.28	27.95	1.12	56.80

[a]In this table, a row is comprised of the area proportion of one land-use type converted into the other land-use types in the study period, as also shown in Tables 4 and 5

Table 4 The transition matrix of land-use types in Yongsheng County from 1994 to 1999

Land-use type	*Water body*	*Paddy field*	*Dry land*	*Urban land*	*Forest land*	*Harvested site*	*Unused land*
Water body	92.76	4.01	0.10	0.53	0.49	0.29	1.82
Paddy field	0.81	52.39	6.25	4.84	2.58	0.86	32.27
Dry land	0.08	2.60	45.63	0.08	15.58	0.21	35.83
Urban land	0.92	35.39	1.45	49.36	1.90	0.36	10.62
Forest land	0.02	0.44	2.67	0.07	88.07	1.93	6.79
Harvested site	0.12	0.48	4.00	0.14	34.98	26.34	33.94
Unused land	0.19	8.20	9.22	0.51	22.05	3.98	55.86

land-use types is about 10% of total area, and paddy fields and unused land are the main transition destinations.

(2) Paddy fields and dry land are two land-use types showing great changes, about 40% to 70% of total area, respectively. The inter-transition between them and unused land is the main change, with a partial transition into urban land and forest land. In each study period, about 30% of paddy fields and dry land are converted into unused land, and 5% to 10% of unused land is converted into paddy fields or dry land. This suggests that most arable land is unstable and of low soil quality, and that the coexistence of abandoned arable land and new cultivated land is a typical land-use characteristic of the agricultural landscape of Yongsheng County.

(3) The area of urban land has steadily increased in both study periods, mainly due to the conversion of paddy fields. There are also transitions from urban land to paddy fields and unused land. In each study period, more than 35% of urban land is converted into paddy fields. These show that rural urbanization and industrialization have taken place in the study area, and there is a strong tradition of land consolidation and rehabilitation.

(4) Forest land is mainly converted into unused land, dry land and harvested sites due to human deforestation and natural burning. In addition, unused land is mainly converted into forest land because of the protection of natural forests and human afforestation.

Change of landscape diversity

The landscape diversity index reflects the difference between the amounts and proportions of various landscape elements. Generally speaking, a high value means that the proportion of various kinds of landscape elements is in balance. On the whole, the degree of landscape diversity in Yongsheng County was relatively low, and the area for each landscape element was comparatively out of balance in proportion. In the study periods, the landscape diversity index rose continuously (Table 5), which reflected a balanced landscape structure as a result of human activities.

Table 5 Change of landscape metrics of the whole landscape in Yongsheng County from 1988 to 1994

Landscape metrics	*1988*	*1994*	*1999*
Landscape diversity index	1.215	1.247	1.306
Landscape contagion index	0.58715	0.57790	0.55998
Landscape fragmentation index	0.04415	0.05008	0.05557

Forest land and unused land dominated the landscape, and the rapid reduction in unused land and continuous growth of other land-use types led to a slow increase in the degree of evenness for each of the landscape elements from 1988 to 1999.

Change in spatial configuration of landscape elements

The landscape contagion index reflects the juxtaposing and clumping of landscape elements. In general, a large value for this index means that the landscape is composed of a small number of clumpy patches, while a small value, in contrast, represents a landscape including many scattered small patches. From Table 5, we can see that the degree of contagion of the landscape in the study area was relatively moderate, with a continuous decrease demonstrating the existence of a few clumpy patches to a low extent and the weakening of their dominance in the landscape.

The landscape fragmentation index reflects human disturbance of the landscape. The fragmentation of the whole landscape in Yongsheng County increased over time (Table 5), which reflected the continuing strengthening of human disturbance in the process of landscape change.

From Table 6, we see that the fragmentation index for dry land, paddy field, urban land, harvested sites and unused land suffered from heavy human disturbance that increased continuously throughout the study period. The index for water bodies decreased, after first rising, with the decreasing trend of forest land. The increase of the fragmentation index for human-managed types of landscape elements supports the random effect of human disturbance, which converted homogeneous patches into heterogeneous patch mosaics. Whereas in 1988, 1994 and 1999, the fragmentation of urban land experienced the greatest human disturbance of all the landscape elements, it was lower than the

Table 6 Change in landscape metrics of landscape elements in Yongsheng County from 1988 to 1994

Landscape metrics		*Paddy field*	*Dry land*	*Forest land*	*Harvested site*	*Urban land*	*Water body*	*Unused land*
Landscape fragmentation index	1988	2997.25	5470.18	1717.86	1430.49	654.16	186.41	3362.63
	1994	4562.36	7631.49	1267.06	1781.50	1169.59	138.02	5462.70
	1999	6405.37	8082.09	1164.29	3590.22	1193.54	165.14	6921.80
Modified fractal dimension index	1988	1.177	1.126	1.266	1.091	1.102	1.257	1.232
	1994	1.155	1.121	1.317	1.108	1.102	1.260	1.199
	1999	1.151	1.127	1.316	1.122	1.118	1.259	1.184

continuing and moderate human disturbance of dry land, paddy fields and unused land. This was partly due to the proportionally small area of urban land resulting from the fragmented landforms and undeveloped social economy in the study area. Also restricted by fragmented landforms, agricultural development was accompanied by the separation of arable land and low agricultural intensive operations, which resulted in the increasing fragmentation index for paddy fields and dry land.

The increase in the fragmentation index for unused land was mainly because of the division of large patches into patch mosaics of different landscape elements, together with the decrease in area of unused land. Also, the decrease in the fragmentation index of forest land primarily resulted from the combination of the formerly dispersed small patches in the process of the formation of new forest land.

Change of patch shape

The fractal dimension index reflects the complexity of the patch within a given observation scale. The modified fractal dimension index consists of information not only about the shape and area but also about the contiguity and evenness of patches. It is, therefore, sometimes more suitable to indicate the change in landscape patterns than the fractal dimension index. Many studies indicate that a small index of modified fractal dimension corresponds to a relatively regular geometry of patches, with a high degree of human disturbance. This is confirmed by a comparison of the modified fractal dimension indices for different landscape elements in Yongsheng County (Table 6).

From Table 6, it is evident that the modified fractal dimension indices of forest land, water bodies and unused land experiencing low human disturbance are obviously larger than those of paddy fields, dry land, urban land and harvested sites experiencing high levels of human disturbance. The increase in the modified fractal dimension indices of forest land and harvested sites shows the reinforcement of the impact of natural processes on the change of corresponding landscape elements.

Ecological effects of land-use change

Integrated ecological effects of land-use change in the whole county

Table 7 shows that the ecological value of land use in Yongsheng County is moderate and increased at an annual average rate of 2.07% during the study periods. The land-use change in the region records the desirable ecological effects of optimizing both the landscape structure and the landscape function, in accord with the actual conditions of the study area. Meanwhile, from 1988 to 1999, the GDP (Gross Domestic Product) index of Yongsheng County increased by 322.16%, at an annual average rate of 29.29%, which suggests that rapid economic development was not at the cost of degradation of the environment and that development was sustainable in terms of LUCC.

Spatial differentiation of ecological effects of land-use change

From Table 7, we can also see that the ecological values of land use in different towns of Yongsheng County differed greatly, with a decrease in the relative differences in the study periods. The maxima were 4.8–1, 3.22- and 3.0-times that of the minima in 1988, 1994 and 1999, respectively.

There were also obvious spatial differences in the ecological effects of land-use change in all 18

Table 7 Change in ecological value of land use in Yongsheng County from 1988 to 1999

Township	*Ecological value*			*Change in ecological value*		
	1988	*1994*	*1999*	*1988–1994*	*1994–1999*	*1988–1999*
Whole county	0.4984	0.5665	0.6118	13.65	8.01	22.76
Yongbei	0.5248	0.5491	0.6292	4.64	14.58	19.90
Jinguan	0.5446	0.4166	0.5012	−23.51	20.31	−7.97
Liangguan	0.3192	0.4124	0.4251	29.22	3.06	33.17
Qina	0.3207	0.3834	0.4334	19.55	13.03	35.13
Renhe	0.5682	0.6093	0.6909	7.23	13.40	21.59
Dongshan	0.7590	0.8376	0.8268	10.35	−1.29	8.93
Dongfeng	0.6134	0.6649	0.6588	8.40	−0.93	7.40
Guanghua	0.7089	0.5741	0.6314	−19.01	9.97	−10.93
Liude	0.5711	0.6306	0.6632	10.41	5.17	16.12
Daan	0.5386	0.5893	0.6359	9.40	7.92	18.06
Taiji	0.1690	0.3951	0.5804	133.82	46.91	243.50
Songping	0.8122	0.7510	0.7764	−7.54	3.38	−4.42
Banqiao	0.2617	0.4468	0.5216	70.70	16.75	99.30
Taoyuan	0.1765	0.2600	0.2756	47.31	6.00	56.15
Pianjiao	0.2653	0.4255	0.4957	60.38	16.48	86.81
Chenghai	0.4923	0.5973	0.6706	21.31	12.27	36.20
Yangping	0.5954	0.7336	0.7036	23.22	−4.10	18.16
Shunzhou	0.4910	0.6005	0.6268	22.31	4.38	27.67

towns, which is an important basis for ecological planning for sustainable development. According to the change in ecological value in the study periods, all 18 towns of Yongsheng County can be classified into three types (Figure 2):

(1) Zone with continuous increase of ecological value (ZCIEV). In this zone, the ecological value of land use increased continuously during the study periods. It included 12 towns, Yongbei, Liangguan, Qina, Renhe, Chenghai, Taoyuan, Pianjiao, Taiji, Shunzhou, Banqiao, Liude, and Daan. The increase in ecological value mainly resulted from a continuous increase in forest land and decrease in unused land.

(2) Zone with an increase after an initial decrease of ecological value (ZIDFEV). In this zone, the ecological value decreased between 1988 and 1994, increased between 1994 and 1999, and again decreased between 1988 and 1999. It included 3 towns, Jinguan, Songping and Guanghua. The decrease in ecological value between 1988 and 1994 was mainly the result of logging of economic forests and of fuelwood collections by local communities, which contributed to the transition from forest land to unused land. Later, between 1994 and 1999, due to tree planting and land reclamation, the area of unused land decreased quickly to the 1988 level. But only half of the decrease in unused land was converted into forest land, and the other half was converted into harvested sites, paddy fields, dry land and water bodies, which resulted in a lower ecological value in 1999 than in 1988.

(3) Zone with a decrease after an initial increase of ecological value (ZDIFEV). In this zone, the ecological value increased between 1988 and 1994, decreased between 1994 and 1999, and increased between 1988 and 1999. It included 3 towns, Dongshan, Yangping and Dongfeng. The increase in ecological value between 1988 and 1994 was mainly the result of tree planting and land reclamation, which produced a great transition from unused land to forest land, harvested sites, paddy fields and dry land. Later, between 1994 and 1999, forest land was partly converted into harvested sites due to the fuelwood collection of local communities, and some paddy fields had to be converted into dry land because of a restriction of agricultural resources such as

Figure 2 Spatial differentiation of the change of ecological value in Yongsheng County

precipitation, which resulted in a higher ecological value in 1999 than that in 1988.

CONCLUSIONS

The study in Yongsheng County indicated that the major land-use changes were the continuous increase in forest land and the rapid decrease in unused land, with an inter-transition between farmland and unused land also happening frequently. The increasing trend in the landscape diversity index meant that the proportion of each landscape element changed to average. Also, the decrease in the fractal dimension of unused land showed that human activity effects were increasing.

The main driving force of land-use change was human activity, such as the protection of natural forests, human afforestation and land reclamation, which resulted in a rapid decrease of unused land and a continuous increase of forest land. Environmental elements, such as landform and heat, were important limiting factors in the process of land-use change. The fragmented topography caused a dominance of small patches and a high fragmentation index of the agricultural landscape. Due to poor soil quality, the abandonment of arable land and land reclamation continued to coexist.

Ecological value calculation showed that land-use change has resulted in positive ecological effects, and that the development was sustainable in terms of LUCC. Distinct spatial differentiation is an important basis for ecological planning for sustainable development.

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