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Responses of Spatial-temporal Variation of Karst Ecosystem Service Values to Landscape Pattern in Northwest of Guangxi, China

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Abstract: The responses of spatiotemporal variation of ecosystem service values (ESVs) to landscape pattern from 1985 to 2005 in a typical Karst area of the northwest Guangxi Zhuang Autonomous Region, China, were examined using remote sensing and geographic information system techniques in this paper. The total ecosystem service values declined significantly from 1985 to 1990, and then increased slowly from 1990 to 2005, almost equaled to the 1985 level. The ecosystem service values tended to decline from the west to the east and from mountainous regions to peak-cluster depression areas in 1985, 1990, 2000 and 2005 respectively. During the period from 1985 to 2005, the ecosystem service values have increased in the middle and eastern parts of the study area. Landscape pattern indices, such as total area, largest patch index, contagion, aggregative index, effective mesh and proportion of like adjacencies, are significantly correlated with ecosystem service values. This suggests that ecosystem service values tend to increase with the growth of patch area and patch connectivity. However, there are negative correlations between ecosystem service values and landscape pattern indices, such as division index and patch richness. It indicates that ecosystem service values decrease with patch fragmentation and patch size shrinkage. The ecosystem conditions in the typical Karst area have been improved because of the control measures of rocky desertification. It is important to protect key landscape types, such as woodland, shrub and grassland, and to increase patch size and connectivity to avoid further fragmentation. Furthermore, it is necessary to reduce disturbances to ensure the growth of ecosystem service values and to facilitate the sustainable development in this region.

Keywords: landscape pattern; ecosystem service values (ESVs); landscape indices; Karst; Guangxi

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1 Introduction

Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily, 1997). They can also be described as goods and services provided by ecosystem which contribute to human welfare directly or indirectly (Costanza *et al*., 1997; Millennium Ecosystem Assessment, 2003). It is urgent to evaluate ecosystem conditions and services value due to resources depletion, environmental degradation and ever increasing human population. To date, there is a growing volume of literatures on ecosystem services assessments (Turner *et al*., 2000; Pan *et al*., 2004; Hein *et al*., 2006; Boerner and Mendoza, 2007; Kroeger and Casey, 2007; Wossink and Swinton, 2007; Chazdon, 2008; Costanza, 2008). The ecosystem service values (ESVs) in various aspects have been studied with different methods. Landscape ecology is the science of studying and improving the relationship between spatial pattern and

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ecological processes on a multitude of landscape scales (Wu, 2006). Landscape pattern analysis is a major focus of landscape ecology. There are many researches focusing on landscape pattern (Kienast, 1993; Hulshoff, 1995; Wilson and King, 1995; Wu, 2000; Fu *et al*., 2001; Drielsma *et al*., 2007; Chen *et al*., 2008). However, these researches have mainly been focused on either ESVs or landscape pattern properties. Little attention has been paid to the relationship between ESVs and landscape pattern. As a matter of fact, landscape pattern may affect ESVs in different ways and at different geographical scales. ESVs may be sensitive to some landscape pattern indices, and they possibly are more tolerant to some others.

Karst area is characterized by poor soil formation ability, thin soil depth, and great surface water leakage (Yuan and Cai, 1988). Once Karst ecosystem degraded, the recovery will be slow and difficult (Yang *et al*., 2008). One of the results of ecosystem degradation in this region is rocky desertification, a landscape similar to desert landscape with high percentage of bedrock after severe disturbances (Yuan and Cai, 1988). As bedrock is widely exposed, land productivity will decline, and the distribution of cropland will be more scattered. Karst region in Southwest China has been one of the most serious areas of poverty and environmental degradation in China (Zhang *et al*., 2010b). Some measures, such as ecological migration and Green for Grain program, have been taken to control rocky desertification in this area. It is necessary to assess the impacts of these measures on landscape pattern and ESVs.

Therefore, it is necessary to explore the responses of spatio-temporal variation of Karst ESVs to landscape pattern changes. A few researches on ESVs of Karst regions in Southwest China have been engaged in (Luo *et al*., 2008; Wu *et al*., 2008; Xiong *et al*., 2008). There are few studies focusing on Guangxi Zhuang Autonomous Region or ESVs (Luo *et al*., 2008; Feng *et al*., 2010; Xie *et al*., 2010). Moreover, little attention has been paid to the relationships between landscape pattern and ESVs in Karst areas. In this paper, we analyzed the relationships between spatio-temporal variation of ESVs and landscape patterns in the northwest of Guangxi, China from 1985 to 2005, using remote sensing and geographic information system techniques with the aim to provide useful information for policy makers who concern about ecological restoration and sustainable development.

2 Methods

2.1 Study area

The study area is located in the northwest of Guangxi, China (23°41′–25°37′N, 104°29′–109°09′E) (Fig. 1), with an area of 71 992 km^2, including 23 counties, and a population of 7.61 × 10^6. The region has a subtropical

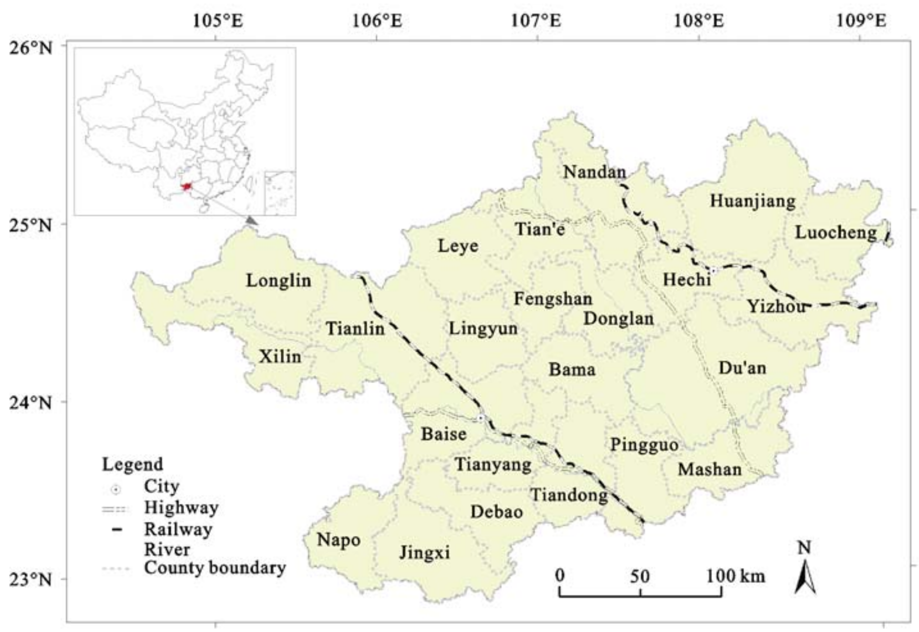

Fig. 1 Location of study area

wet monsoon climate with a mean annual temperature of 19.5℃. The amount of annual precipitation varies from 1000 mm to 1600 mm. Elevation in this hilly region ranges from 100 m to 2000 m above sea level. Dominant vegetation communities are subtropical mixed evergreen and deciduous forests. The Karst landforms are very typical with a full suite of Karst landforms, including poljes, cockpits and towers. It is a mountainous agriculture region with limited area and low quality of cropland. There are always conflicts among the demands for agricultural development, urbanization, and ecosystem conservation.

2.2 Data acquisition and preprocessing

A digital elevation model (DEM, 100 m × 100 m resolution) and Landsat7 TM images (7 bands, orbits 125-42, 125-43, 125-44, 126-42, 126-43, 126-44, 127-42, 127-43, 127-44, and 128-43 in 1985, 1990, 2000 and 2005) were downloaded from the Data-sharing Network of Earth System Science in China (http://www.geodata.cn). Climate and radiation datasets, including annual precipitation, average temperature, total radiation and net radiation, were obtained from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn).

ARCGIS 9.0 and ERDAS IMAGINE 9.0 were used to classify landscape types. The landscape was classified into nine categories, including paddy, dry land, woodland, shrub, scattered woodland, grassland, water area, residential land and barren rock. Information of these landscape types was extracted from Landsat TM imagery with ERDAS using a supervised classification method (a maximum likelihood classifier). Overall classification accuracies were 71.88%, 81.88%, 85.54% and 87.56% in 1985, 1990, 2000 and 2005, respectively. Kappa coefficients of classification were 0.66, 0.75, 0.78 and 0.80, respectively. Weather and radiation datasets were interpolated using the spatial analysis tool in ARCGIS. All data were projected or re-projected to the Albers Conical Equal Area projection (Krasovsky Spheroid) and re-sampled to a 100 m × 100 m pixel spacing.

2.3 Calculation of ecosystem service values

Based on previous studies (Running and Coughlan, 1988; Li, 1999; Jiang *et al*., 2007; Zhang *et al*., 2007; Cao *et al*., 2008; Zhang *et al*., 2009; Zhao *et al*., 2010), we used models including net primary productivity (NPP), gas regulation, water conservation, soil reservation, organic production, nutrient cycling, soil information, biodiversity, recreation and culture, and total ESVs for each of the nine landscape types. A formula of photosynthesis and respiration was used to obtain the ecosystem services of gas regulation (Jiang *et al*., 2007). Water conservation was calculated according to the water-holding capacity of soil and flow (Li, 1999). The amount of soil reservation was estimated by the differences between potential soil erosion and real soil erosion. The real soil erosion was calculated through vegetation coverage and slope based on the classification standard of soil erosion (SL190-96) for China. The potential soil erosion was determined from soil erosion of 5% vegetation coverage (Jiang *et al*., 2007). Organic production values were calculated by substitute NPP with equivalent amount of heat of carbolic and standard coal. The value of nutrient cycling was counted based on NPP (Cao *et al*., 2008), with the ratio and prices of nitrogen (N), phosphorus (P), potassium (K), which were based on the field-sampled results (Zhang *et al*., 2007). Models of total ESVs are as follows:

$$V = \sum_{c=1}^{n}\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}(x) \times V_{ci} \times S_{ij} \quad (1)$$

$$R_{ij}(x) = \left(\frac{NPP_j(x)}{NPP_{\text{mean}}} + \frac{f_j(x)}{f_{\text{mean}}} \right) \Big/ 2 \quad (2)$$

where V is the total ESVs of this study area; c is landscape type (c = 1, 2, 3, …, 9, indicating paddy, dry land, woodland, shrub, scattered woodland, grassland, water area, residential land and barren rock respectively); i indicates various types of ESVs (i = 1, 2, 3, …, 9, i.e., gas regulation, water conservation, soil reservation, organic production, nutrient cycling, soil information, biodiversity, recreation and culture). V_{ci} is the ecosysterm service value per unit area of land use types. j is the number of pixel (j = 1, 2, 3, …, 33215). S_{ij} is the size of pixel, and R_{ij} is the adjustment coefficient, which is determined by quality of landscape types. $NPP_j(x)$, NPP_{mean}, $f_j(x)$, f_{mean} is NPP of pixel, average NPP, vegetation coverage of pixel, and average vegetation coverage respectively.

2.4 Calculation of landscape pattern indices

Landscape pattern indices were calculated for each county. Therefore, there were totally 92 sample data in

1985, 1990, 2000 and 2005. We selected thirteen indices of landscape pattern, including total area (TA, ha), number of patches (NP), patch density (PD), largest patch index (LPI), contagion (CON), patch cohesion index (COH), aggregative index (AI), effective mesh (MES, ha), proportion of like adjacencies (PLA, %), division index (DIV), patch richness density (PRD), Shannon′s diversity index (SHD), and Shannon′s evenness index (SHE). They were calculated using Fragstats 3.3. These landscape pattern indices and total ESVs were then used respectively for further regression analysis in SPSS 13.0.

3 Results and Analyses

3.1 Historical changes of ecosystem service values

There was a general increase trend in ESVs in the northwest of Guangxi, China (Table 1). The total ESVs were 1.097×10^{11} yuan, 8.879×10^{10} yuan, 1.034×10^{11} yuan and 1.063×10^{11} yuan in 1985, 1990, 2000, and 2005 respectively. ESVs decreased 3.10% from 1985 to 2005, which might be caused by the shifts of land use types.

Woodland and shrub are the two main ESV contributors in the study area. ESVs from both were over 70% of the total ESV. The area of woodland accounted for 25.13%, instead, it generated 44.08% of the total ESVs in 2000. Therefore, the decline in ESVs might mainly be caused by the decrease of the area of woodland and shrub from 1985 to 2000. The decrease of ESVs of woodland was about 9.087×10^9 yuan from 1985 to 2005. The increase of ESVs caused by the expansion of scattered woodland was not large enough to offset the decrease during this period. As a result, the total ESVs decreased by 2.086×10^{10} yuan from 1985 to 1990. However, the total ESVs increased by 1.460×10^{10} yuan from 1990 to 2000. The net increase in ESVs was about 2.873×10^9 yuan from 2000 to 2005, mainly due to the increase of shrub, scattered woodland and grassland.

3.2 Distribution characteristics of ecosystem service values

ESVs of the study area decreased from the west to the east in 1985, 1990, 2000 and 2005 respectively (Fig. 2). ESVs in the west were higher mainly due to the higher vegetation coverage. The average ESVs were more than 15 000 yuan/ha in the west, where is the main natural reserve for endangered wildlife species in Guangxi. On the contrary, the ESVs were lower than 10 000 yuan/ha in the central part of the region due to low vegetation coverage and serious Karst rocky desertification. Rocky desertification mainly occurs in the central, the southwest, and peak-cluster depressions of Guangxi, including the counties of Pingguo, Du′an, Mashan, Bama, Donglan, Fengshan, Debao and some peak-cluster depression of Jingxi, Napo, Mashan, Du′an (Yang, 2003). These counties are all located in the middle or the east part of the study area.

For ESVs, the spatial variation was different from the spatial distribution in the periods of 1985–1990, 1990–2000, 2000–2005 and 1985–2005 (Fig. 3). ESVs decreased in the whole area from 1985 to 1990, and then increased mostly in the northern part of the study area from 1990 to 2000, and from 2000 to 2005 they also increased in the northwest portion while reduced in the southeast. During 1985–2005, the ESVs increased in the

Table 1 Ecosystem service values of different landscape types in study area from 1985 to 2005 ($\times 10^8$ yuan)

		Paddy	Dry land	Woodland	Shrub	Scattered woodland	Grassland	Water area	Residential land	Barren rock	Total
1985	ESVs	85.38	56.89	437.93	342.94	93.30	67.85	5.44	2.36	4.42	1096.52
	Percent (%)	7.79	5.19	39.94	31.28	8.51	6.19	0.50	0.22	0.40	100.00
1990	ESVs	70.42	32.83	334.33	288.09	94.35	59.76	3.43	1.52	3.16	887.89
	Percent (%)	7.93	3.70	37.65	32.45	10.63	6.73	0.39	0.17	0.36	100.00
2000	ESVs	67.93	44.01	455.69	305.78	89.27	62.93	2.81	1.54	3.88	1033.84
	Percent (%)	6.57	4.26	44.08	29.58	8.63	6.09	0.27	0.15	0.38	100.00
2005	ESVs	83.96	55.79	347.06	365.18	110.27	84.74	7.49	3.44	4.65	1062.57
	Percent (%)	7.90	5.25	32.66	34.37	10.38	7.98	0.70	0.32	0.44	100.00
1985–2005	ESVs	–1.42	–1.10	–90.87	22.24	16.96	16.89	2.04	1.07	0.23	–33.95
	Percent (%)	–1.66	–1.93	–20.75	6.49	1.18	24.89	37.54	45.48	5.26	–3.10

central and eastern part of the study area. Nevertheless, the decrease of ESVs in many parts of the west indicates the degraded ecosystem conditions. It was mainly because of the policies of forest harvesting in 1990s, ecological migrants and ′Green for Grain′ program in the 21st century. With the ever increasing environment protection consciousness, the central and local governments at different levels started the ′Green for Grain′ program in the following years (Yang, 2003). Therefore, the ecosystem services increased in most central and east part of the study area because of control measures and policies of rocky desertification, while it got worse in many parts of the west, where tropical rain forests and subtropical evergreen broad-leaved forest distributed. Ecosystem management in this area should be paid more attention.

3.3 Relationship between ecosystem service values and landscape pattern

There are significant correlations between ESVs and landscape pattern ($p < 0.01$) (Table 2), which explained that landscape pattern affected ESVs significantly. For example, the correlation coefficients between effeitive mesh size and ESVs, total area and ESVs are 0.795 and 0.807, respectively, which indicates that the importance of effective mesh size and total area to ESVs. The correlation coefficients between PRD and ESVs, DIV and ESVs are –0.702 and –0.694, which showed that there existed significantly negative effect between patch richness density, landscape division index and ESVs.

Concerning the relationship of ESVs with landscape pattern, landscape pattern indices, such as total area (TA), largest patch index (LPI), contagion (CON), aggregative index (AI), effective mesh size (MES) and proportion of like adjacencies (PLA) *etc*., were significantly correlated with ESVs ($p < 0.01$). It indicated that ESVs had positive correlations with patch area and patch connectivity. There were negative correlations between ESVs and other landscape pattern indices, such as division index (DIV) and patch richness (PR) (Fig. 4). The results showed that ESVs decreased with the development of patch fragmentation and shrinking of patch sizes. Therefore, it is important to protect key landscape types such as woodland, shrub and grassland,

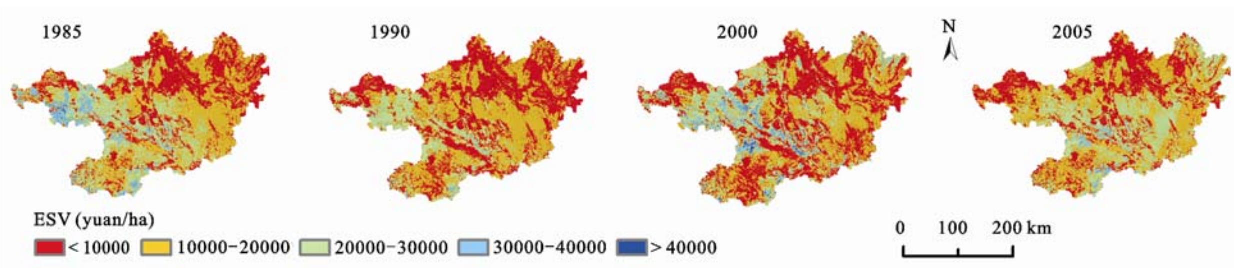

Fig. 2 Spatio-temporal distribution of ecosystem service values

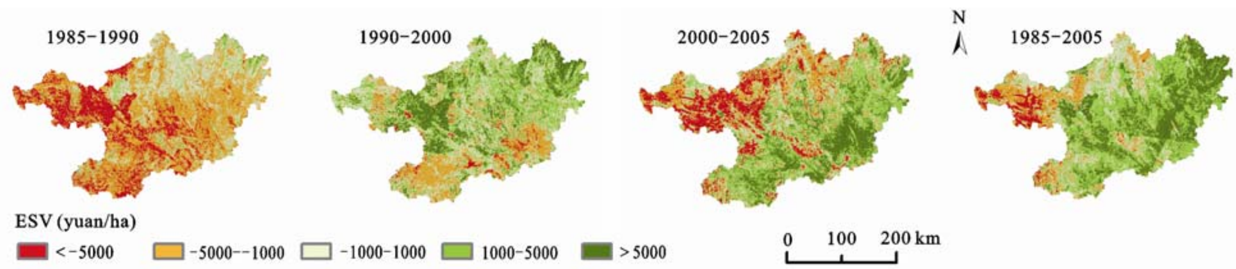

Fig. 3 Spatio-temporal changes of ecosystem service values

Table 2 Correlation coefficients between ecosystem service values and landscape pattern indices

	TA	NP	PD	LPI	CON	PLA	COH	DIV	MES	PRD	SHD	SHE	AI
ESVs	0.807**	0.423**	–0.333**	0.659**	0.547**	0.358**	0.414**	–0.694**	0.795**	–0.702**	–0.572**	–0.594**	0.344**

Notes: TA, total area; NP, number of patches; PD, patch density; LPI, largest patch index; CON, contagion index; PLA, proportion of like adjacencies; COH, patch cohesion index; DIV, landscape division index; MES, effective mesh size; PRD, patch richness density; SHD, shannon′s diversity index; SHE, Shannon′s Evenness index; AI, aggregation index; ESVs, ecosystem service values. **, significant at 0.01 level
Source: Zhang *et al*., 2010a

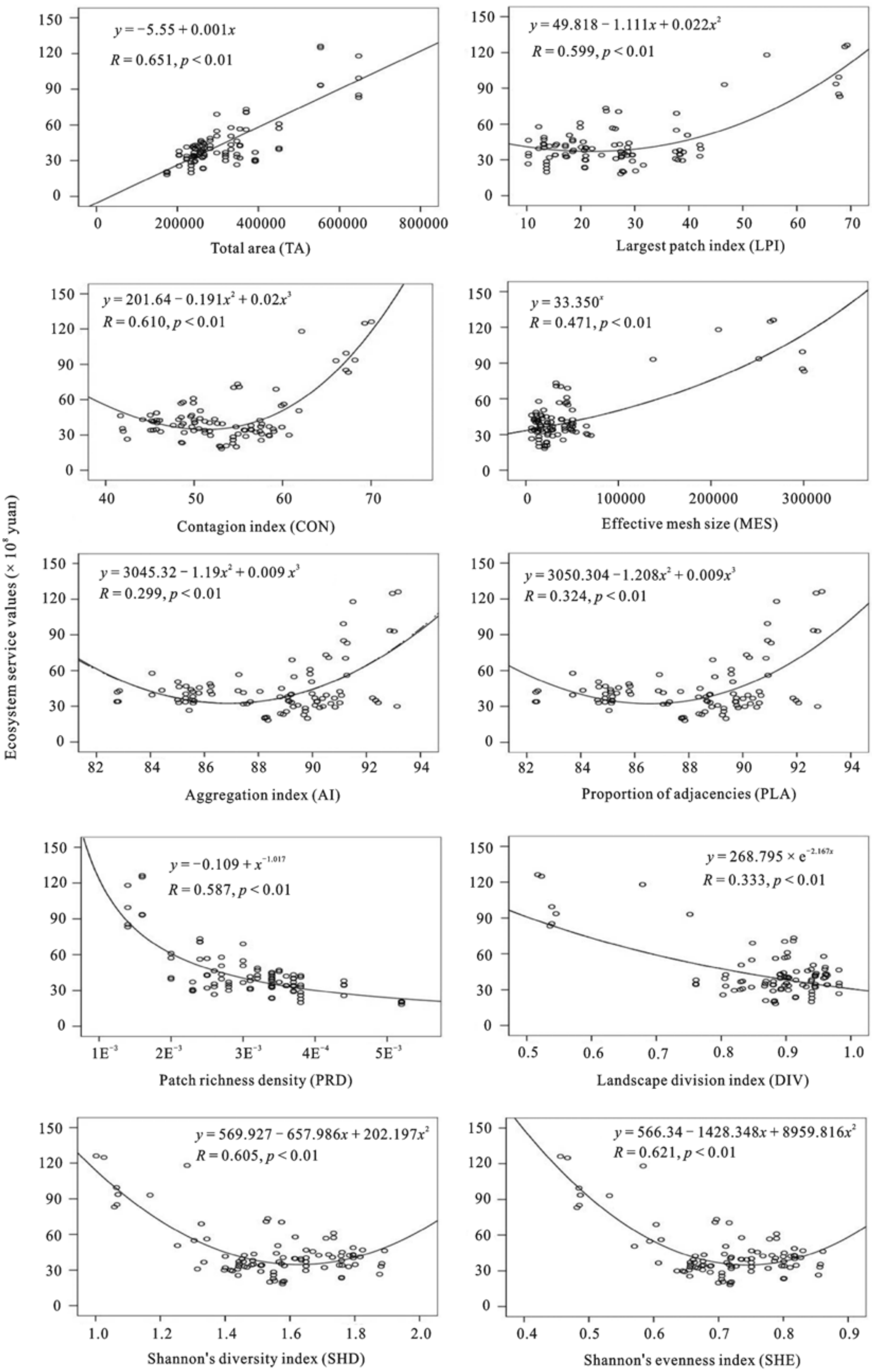

Fig. 4 Relationships between ecosystem service values (ESVs) and landscape pattern indices

and to increase patch size and connectivity to avoid further fragmentation. Moreover, it is necessary to reduce frequency and severity of disturbances to ensure the growth of ESVs and to facilitate the sustainable development.

4 Conclusions

In this paper, the relationships between spatio-temporal variation of ESVs and landscape pattern indices are analyzed in the northwest of Guangxi, China from 1985 to 2005. The total ESVs declined significantly from 1985 to 1990, and then increased slowly from 1990 to 2005. Four important land use types (woodland, shrub, scattered woodland and grassland) contribute to the majority of ESVs. The ESVs tended to decline from the west to the east. The ESVs are more than 15 000 yuan/ha in the west of the study area, but they are less than 10 000 yuan/ha in the central part of the area due to low vegetation coverage, serious peak-cluster depression and Karst rocky desertification. From 1985 to 2005, in the central and eastern part of the study area, ecosystem conditions were improved and the ESVs increased. Considering the relationships of ESVs with landscape pattern, ESVs tend to increase with the growth of patch area and patch connectivity, and decrease with the development of patch fragmentation and shrinking of patch sizes. Because of the application of rocky desertification control policies, the ecosystem conditions in the typical Karst area are improving. It is important to protect key landscape types such as woodland, shrub and grassland and to increase patch size and connectivity to avoid further fragmentation. It is necessary to reduce disturbances to ensure the growth of ESVs and to facilitate sustainable development.

There are two issues should be paid attention to in the further studies. One is that the relationships between ESVs and landscape pattern indices are conditional. For example, ESVs tend to increase with the growth of patch area and patch connectivity, which usually happen in the woodland or shrub, not all the landscape types. The other one is about conservation of Karst area. We should not take precedence over the uncontrolled reclamation of these areas for economic purposes in land use. More detailed researches on the impacts of Karst reclamation projects on the ecosystem services provided in Karst areas are necessary.

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