Environmental Management (2011) 48:933–944
DOI 10.1007/s00267-011-9735-z

Spatiotemporal Variation of Karst Ecosystem Service Values and Its Correlation with Environmental Factors in Northwest Guangxi, China

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Received: 7 April 2010 / Accepted: 25 July 2011 / Published online: 24 August 2011

Abstract In this investigation we analyzed the spatiotemporal variation of ecosystem service values (ESVs) and its correlation with numerous environmental factors (EFs) for the karst region of Northwest Guangxi, China, from 1985 to 2005 using remote sensing, geographic information systems (GIS) and statistical techniques. The results indicate that historically ESVs for this karst region decreased from 1985 (109.652 billion Yuan) to 1990 (88.789 billion Yuan) and then increased at the turn of the twenty-first century. However, the ESVs in both 2000 (103.384 billion Yuan) and 2005 (106.257 billion Yuan) never achieved the level recorded in 1985. The total of nutrient cycling, organic production and gas regulation combined were 72.69, 64.57, 70.18 and 72.10% of ESVs in 1985, 1990, 2000 and 2005, respectively. In contrast, the ESVs of water conservation, soil reservation, recreation and culture were determined to be relatively low contributing only 17.44, 23.82, 19.26 and 24.76% of total ESVs, respectively, during these four years. With regards to the spatial distribution of ESVs, larger values were recorded in the west and smaller ones recorded in the east. The most significant factors that were deemed to influence ESVs are annual rainfall, per capita cropland, slope and vegetation coverage. Annual rainfall and slope exert a negative force, whereas per capita cropland and vegetation coverage exert a positive force on ESVs. The results of the study would suggest that ecosystem conditions of this important karst region have been improved as the result of the implementation of rocky desertification control policies.

Keywords Karst · Northwest Guangxi, China · Ecosystem service values (ESVs) · Spatiotemporal variation · Environmental factors (EFs) · Canonical correspondence analysis (CCA) · Remote sensing · Geographic information systems

Introduction

Ecosystem services are the conditions and processes through which natural ecosystems and species that comprise them, sustain and fulfill human life (Daily 1997). They can also be described as goods and services provided by the ecosystem which contribute to human welfare directly or indirectly (Costanza and others 1997; Millennium Ecosystem Assessment 2003). With current issues of resources depletion, environmental degradation and ever increasing human population, it is urgent to evaluate ecosystem conditions and services values. Consequently, the science of ecosystem services is viewed as the first major ecological issue of the twenty-first century (Palmer and others 2004). According to Ecological Society of England, it is also the first theme of 100 ecological problems that are relevant to policy making (Sutherland and others 2006). As a result, there is a growing volume of literature on ecosystem services assessments (e.g., Turner and others 2000; Boerner and Mendoza 2007; Kroeger and Casey 2007;

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Wossink and Swinton 2007; Chazdon 2008; Costanza 2008; Norgaard and Jin 2008). However, these studies of the ecosystem service values (ESVs) employ different methods and examine various facets of these systems. For example, Costanza (2008) found that multiple classification systems of ecosystem services are required and thus developed a classified eco-services table based on their spatial characteristics and a classified ecosystem services table based on their excludability and rivalness. Kreuter and others (2001) explored the change in ecosystem service values in the San Antonio area, Texas, using LANDSAT images from 1976, 1985 and 1991 to produce coefficients as proposed by Costanza and others (1997). Zhao and others (2004) created an ecosystem service value assessment on land use change for Chongming Island, China between 1990 and 2000. Based on these results, they concluded that future land-use policy formulation should give precedence to the conservation of these ecosystems under uncontrolled reclamation and that further land reclamation should be based on rigorous environmental impact analyses. Petrosillo and others (2009) researched the effectiveness of different conservation policies on the security of natural capital and the natural capital flow variation in southern Italy using the economic valuation of ecosystem goods and service and the temporal dynamics of land-use/land-cover mosaics. They found that not all environmental conservation policies have played an equal role in fostering the maintenance of natural capital. Moreover, they suggested that the presence of a local management authority who can set some limits on human activities that cause landscape changes can increase the security of natural capital. Moreover, they concluded that the management of these areas as part of a network of natural parks seems to be more effective for the maintenance of natural capital flow (Petrosillo and others 2010).

The aforementioned research endeavors on ecosystem services assessments have so far been focused primarily on forest, wetland, urban, and grassland ecosystems with very little attention being paid to karst areas. Karst terrain and carbonate dominated area accounts for about 15% of the world's land area or about 2.2 million km^2, and is home to approximately 1 billion people (i.e. 17% of the world's population) (Yuan and Cai 1988). Karst area is also considered one of the most fragile systems in the world (Parise and others 2008) being characterized by poor soil formation ability, thin soil depth (generally not more than 10 cm), and poor surface water retention (i.e. infiltration coefficient of 0.3–0.6 or even 0.8) (Yuan and Cai 1988). Consequently, the recovery of a degraded karst ecosystem can be relatively slow and difficult in comparison to other ecosystems.

One of the most prominent results of ecosystem degradation in the karst region of Northwest Guangxi, China, is rocky desertification. Following this process a desert like landscape with high percentage of bedrock develops after severe disturbances (Yuan and Cai 1988). As the bedrock is widely exposed, land productivity declines and the distribution of cropland, which is an important index of environmental capacity and potential living space for human, becomes more scattered. As a result of this ongoing process, the karst region in southwest China has become one of the most outstanding areas of economic poverty and environmental degradation in China (Yuan and Cai 1988). To counter this situation, measures have been taken to alleviate poverty and to control the rocky desertification process. Specific countermeasures so far implemented include ecological migration, the Green for Grain program and environmental migration (Zhang and others, in press; Yang and others, in press). However, to date there have not been studies to examine the efficiency of these ecological projects upon the karst ecosystem functions.

The focus of this investigation is to monitor the karst ecosystem condition in this region and to determine how this karst ecosystem provides goods and services for human society. It is anticipated that this evaluation will assist ecosystem management to achieve sustainable development for this fragile environment. Up to now, there have been only a few studies on ESVs of karst regions in southwest China (Li and others 2005; Yang and Peng 2007; Wu and others 2008). These studies either focus on areas other than the Guangxi region or have examined a few aspects of ESVs. For example, Li and others (2005) assessed the ESVs of Maolan karst forest and Yang and Peng (2007) examined only the eco-hydrological functions of the karst forest ecosystems in the Guizhou region. More recently, Wu and others (2008) evaluated the ESVs of a restored secondary forest in the karstic-rocky hills in Nongla National Medicine Nature Reserve, Guangxi. In this investigation we analyze the spatio-temporal variation of ESVs and its correlation with environmental factors (EFs) in NW Guangxi, China from 1985 to 2005, using remote sensing, geographic information systems (GIS) and statistical techniques with the aim to provide useful information for policy makers in order to implement effective planning of ecological restoration, reconstruction, and sustainable development.

Study Area and Methods

Study Area

The study area is located in NW Guangxi, China (104°29′–109°09′E, 23°41′–25°37′N) (Fig. 1), which includes 23 counties covering an area of 71,992 km^2 and sustaining a population of 7.97 million (2009). The region has a subtropical wet monsoon climate with an annual temperature 19.5°C and an annual precipitation that varies between 1,000 and 1,600 mm. The elevation in this hilly region ranges from 100 to 2,000 m above sea level and the dominant vegetation communities are mixed subtropical evergreen and deciduous forests. The karst landforms are very typical in this region and provide a full suite of landforms types including poljes, cockpits, towers and dolines. Consequently, the region supports a mountainous agricultural region where the cropland areas are generally not fertile due to the influence of this geological backdrop. Only 53.58% of cropland has relatively high productivity and the best arable lands are mainly found in flat areas located in karst valleys, or closed depressions, where major settlements are also situated. As a result there are always conflicts resulting from the demands for agricultural development and the demands for ecosystem conservation.

Data Acquisition and Preprocessing

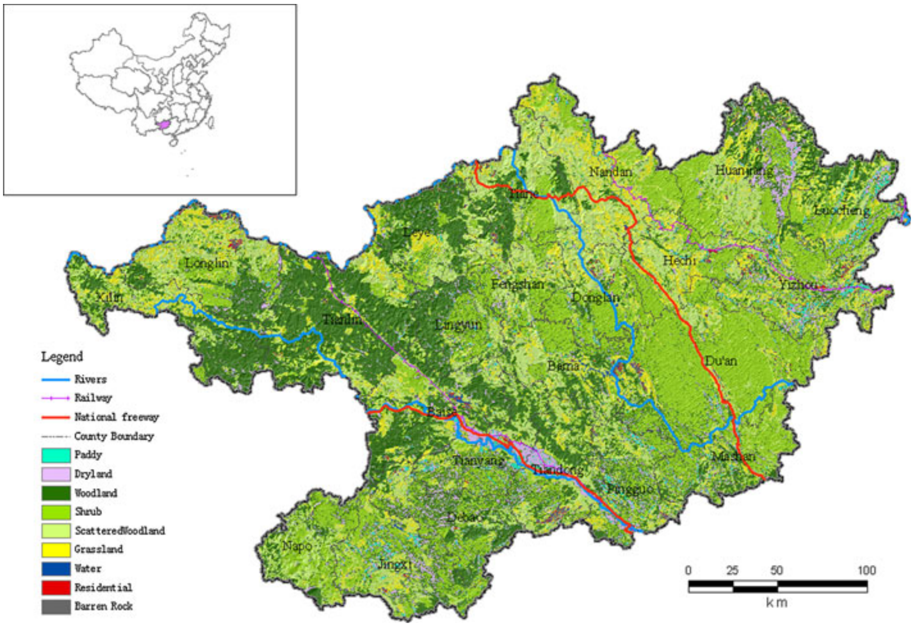
A Digital Elevation Model (DEM, with a resolution of 100 m × 100 m) and Landsat TM images (7 bands, orbits 125-42, 125-43, 125-44, 126-42, 126-43, 126-44, 127-42, 127-43, 127-44, and 128-43 in 1985, 1990, 2000 and 2005) were downloaded from the Data-sharing Network of Earth System Science in China (www.geodata.cn). Weather and radiation datasets, including annual rainfall, average temperature, extreme temperature, total and net radiation, at 97 stations from 1985 to 2005 were collected from the China Meteorological Data Sharing Service System (cdc.cma.gov.cn).

ArcGIS 9.0 (Environment Systems Research Institute) and ERDAS IMAGINE 9.0 (Leica) were used to prepare data and for spatial analysis. Land use/land cover (LULC) was classified into nine categories, including paddy, dry land, woodland, shrub, scattered woodland, grassland, water area, residential and barren rock. Forest coverage was extracted from the Landsat TM images using the Normalized Difference Vegetation Index and the remaining LULC were determined from the Landsat TM images using a supervised classification method (maximum likelihood classifier). To validate the classifications for 1985 and 1990, 1:47,000 color infrared aerial photographs taken in the 1980s and 1990s were referred to and the accuracy of the classifications determined. The overall classification accuracies were 71.88% for 1985 and 81.88% for 1990 with Kappa coefficients of 0.66 and 0.75, respectively. The 2000 and 2005 classifications were evaluated using field data collected in 2000 and 2008. The overall accuracies for these classifications were 85.54 and 87.56%, respectively, with Kappa coefficients of 0.78 and 0.80. Weather and radiation datasets were interpolated (i.e., Kriging) in ARCGIS 9.0. All data were projected or re-projected to the same projection (Albers Conical Equal Area projection, Krasovsky Spheroid) and then re-sampled to a 100 m × 100 m pixel spacing.

ESVs Calculation

We developed models to calculate the net primary productivity (NPP), gas regulation, water conservation, soil reservation, organic production, nutrient cycling, soil information, biodiversity, recreation and culture, and for

Fig. 1 Location of the study area in China



the total ESVs for each of the nine LULC. This approach was based on the methods proposed from previous studies. For example, a formula of photosynthesis and respiration was used to obtain the ecosystem services of gas regulation (Jiang and others 2007). Water conservation was calculated according to the water-holding capacity of soil and the flow as proposed by Li and others (1999). The amount of soil reservation was estimated by the difference between the potential soil erosion and the 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 and others 2007). Organic production values were calculated by substituting NPP with equivalent amount of heat of carbolic and standard coal. The value of nutrient cycling was counted based on NPP (Cao and others 2008) and the ratio and prices of nitrogen (N), phosphorus (P), potassium (K), which were based on in situ results of our research group (Zhang and others 2007).

Models of NPP calculation are as follows:

$$NPP(x,t) = APAR(x,t) \times \varepsilon(x,t) \tag{1}$$

$$APAR(x,t) = SOL(x,t) \times FPAR(x,t) \times 0.5 \tag{2}$$

$$\varepsilon(x,t) = T_{\varepsilon 1}(x,t) \times W\varepsilon(x,t) \times \varepsilon_{\max} \tag{3}$$

$$T_{\varepsilon 1}(x,t) = 0.8 + 0.02 \times T_{opt}(x,t) - 0.0005 \times \left[T_{opt}(x,t)\right]^2 \tag{4}$$

$$W_{\varepsilon}(x,t) = 0.5 + 0.5 \times \frac{E(x,t)}{E_p(x,t)} \tag{5}$$

$$E(x,t) = \frac{P(x,t) \times R_n(x,t) \times \left[(P(x,t))^2 + (R_n(x,t))^2 + P(x,t) \times R_n(x,t)\right]}{[P(x,t) + R_n(x,t)] \times \left[(P(x,t))^2 + (R_n(x,t))^2\right]} \tag{6}$$

$$E_{\rho}(x,t) = \left(E(x,t) + E_{\rho 0}(x,t)\right)/2 \tag{7}$$

where $APAR(x,t)$ is absorbed photosynthesis availability radiation, $\varepsilon(x,t)$ is light energy utilization, $FPAR(x,t)$ is the fraction of photosynthesis active radiation, $SOL(x,t)$ is the solar radiation, $T_{\varepsilon 1}(x,t)$ and $W_{\varepsilon}(x,t)$ are the effect of temperature and water on light energy utilization respectively; $T_{opt}(x,t)$, $p(x,t)$ and $R_n(x,t)$ are the annual average temperature, rainfall, and radiation; $E(x,t)$ and $E_{\rho}(x,t)$ are respectively actual and potential evapotranspiration. $E_{\rho 0}(x,t)$ is the local available evapotranspiration, which is counted by the vegetation-climate model of Thomthwaite (1948). $\varepsilon_{\max}$ is the max light energy utilization, which has different values with different vegetation types. It was counted through the simulation result of the eco-physiological process model (BIOME-BGC) to ten vegetation types as expressed by Running and Coughlan (1988).

Models of total ESVs are:

$$V = \sum_{C=1}^{n} \sum_{i=1}^{n} \sum_{j=1}^{m} R_{ij}(x) \times V_{Ci} \times S_{ij} \tag{8}$$

$$R_{ij}(x) = \left(\frac{NPP_j(x)}{NPP_{\text{mean}}} + \frac{f_j(x)}{f_{\text{mean}}}\right)/2 \tag{9}$$

where V is the total ESVs of this study region, $c = 1, 2, 3,\ldots,n$, is the type of LULC. $i = 1, 2, 3,\ldots,i$, indicates various types of ESVs. V_{ci} is the per unit area values of any service values of LULC; $j = 1, 2, 3,\ldots,j$, is the number of pixel, S_{ij} is the size of pixel, and R_{ij} is the adjustment coefficient, which is determined by quality of LULC. $NPP_j(x), NPP_{\text{mean}}, f_j(x), f_{\text{mean}}$ is NPP of pixel, average NPP, vegetation coverage of pixel, and average vegetation coverage respectively.

Canonical Correspondence Analysis (CCA)

CCA is a multivariate direct gradient analysis method that has become widely used in ecology to examine the relationships between community structure and environmental variables. It is a method of measuring the linear relationship between two multidimensional variables. This method has been applied to scrutinize the relationship between two group variables (Ter Braak 1986, 1994). The results of CCA are generally shown in figures with a two-dimensional map having both horizontal and vertical axis and some vectors. The angle of the vector and axis represents the size of correlation with the smaller angle size representing a larger power of correlation. The length of the vector represents the strength of environmental impacts. Finally, the direction of the vector and axis determines whether the correlations are positive or negative.

In the analysis, ecosystem-services (gas regulation, water conservation, soil reservation, organic production, nutrient cycling, soil information, biodiversity, recreation and culture) were treated as samples and environmental variables (annual rainfall, DEM, rock types, per capita cropland, vegetation types, soil types, vegetation coverage) as EFs. CCA was carried out using CANOCO (Ter Braak 1994). All environmental variables were standardized using SPSS 11.0 (IBM) prior to the application of CCA.

Results

Temporal Changes of LULC

LULC in this area had changed dramatically from 1985 to 2005 (Table 1). The main covers of NW Guangxi were determined to be woodland, shrub, scattered woodland and grassland. Combined they accounted for about 70% of the total area. Shrub, a transitional cover type between grassland and woodland, ranked as first amongst all cover types for all 4 years. The percentage of residential, paddy, dry land, and water area were small (the total ratios were 15.62, 14.40, 15.74, 15.46%, respectively, in the 4 years). From 1985 to 2005, significant change of the composition of land cover types was observed (Table 1). The area of woodland decreased from 25.21% of the total area in 1985 to 23.10 % in 2005, with a reduction of 1,527.10 km^2 (or 8.45% of total woodland area in 1985). The area of scattered woodland was relatively stable at 13,971.00 km^2 in 1985 and 14,619.40 km^2 in 2005. Scattered woodland is also considered a transitional class, in this case between shrub and woodland. The area of paddy was 5,246.17 km^2 in 1985 and 4,945.50 km^2 in 2005. As for barren rock the area of coverage remained relatively stable at 678.37 km^2 in 1985 and 687.63 km^2 in 2005. The residential area was small which was expected given that this region has remained a relatively rural region. However, there was still an expansion of residential area with a 262.39 km^2 coverage in 1985 that increased to 357.79 km^2 in 2005. In contrast, the area of grassland was up by 17.87% with 6,954.04 km^2 in 1985 and 8,196.54 km^2 in 2005. This high transition rate to grassland from other land covers can be attributed in part to the dry land (561.40 km^2).

Historical Changes of ESVs

The results suggest that there has been a general decreasing trend in ESVs in NW Guangxi. The total ESVs were 109.652 billion Yuan, 88.789 billion Yuan, 103.384 billion Yuan and 106.257 billion Yuan in 1985, 1990, 2000, and 2005, respectively (Table 2). It is noted that ESVs of 1990 was the lowest, which was mostly the result of severe karst rocky desertification. The percentage of ESVs decreased by 3.10% from 1985 to 2005, which resulted from shifts of LULC. The increasing ESVs from grassland can not balance the decreased ESVs from woodland.

Woodland and shrub were determined to be the two main ESV contributors in the study area. ESVs from both contributed to over 70% of total ESV. The area of woodland was 25.13% but it generated 44.08% of the total ESVs in 2000. From 1985 to 2000, the decline in ESVs was caused mainly by the decrease of the area of woodland and shrub. The decrease of woodland and shrub was about 10.36 billion Yuan and 5.485 billion Yuan respectively. From 1985 to 1990 the increase of ESVs caused by the expansion of scattered woodland was not large enough to offset the decrease. As a result, the total ESVs decreased by 20.863 billion Yuan (from 109.652 billion to 88.789 billion Yuan). However, the total ESVs increased by 14.595 billion Yuan from 1990 to 2000. This increase was caused primarily by the increase of woodland area. The net increase in ESVs was about 2.873 billion Yuan from 2000 to 2005, as the result of increases of shrub, scattered woodland and grassland.

Table 1 Land use/land cover (LULC) changes in Northwest Guangxi, China from 1985 to 2005

	1985		1990		2000		2005		1985–2005		
	Area/km^2	%	Area/km^2	%	Area/km^2	%	Area/km^2	%	Area/km^2	%	%/year
Paddy	5,246.17	7.32	5,514.51	7.69	5,210.53	7.28	4,945.50	6.91	−300.67	−5.73	−0.29
Dry land	5,296.07	7.39	4,167.18	5.81	5,328.72	7.44	5,328.77	7.44	32.70	0.62	0.03
Woodland	18,065.80	25.21	16,607.70	23.17	17,996.30	25.13	16,538.70	23.10	−1,527.10	−8.45	−0.42
Shrub	20,810.30	29.04	20,833.00	29.07	20,783.90	29.02	20,470.60	28.60	−339.70	−1.63	−0.08
Scattered woodland	13,971.00	19.49	15,721.20	21.93	13,944.00	19.47	14,619.40	20.42	648.40	4.64	0.23
Grassland	6,954.04	9.70	7,525.40	10.50	6,927.07	9.67	8,196.54	11.45	1,242.50	17.87	0.89
Water	385.65	0.54	381.61	0.53	437.93	0.61	438.76	0.61	53.11	13.77	0.69
Residential	262.39	0.37	268.21	0.37	294.71	0.41	357.79	0.50	95.40	36.36	1.82
Barren rock	678.37	0.95	655.05	0.91	685.99	0.96	687.63	0.96	9.26	1.37	0.07
Total	71,669.79	100	71,673.86	100	71,609.15	100	71,583.69	100	–	–	–

Table 2 Ecosystem service values (ESVs) based on LULC types in Northwest Guangxi, China

	Paddy	Dry land	Wood land	Shrub	Scattered woodland	Grass land	Water	Residential	Barren rock	Total
1985										
10^8 Yuan	85.38	56.89	437.93	342.94	93.30	67.85	5.44	2.36	4.42	1,096.52
%	7.79	5.19	39.94	31.28	8.51	6.19	0.5	0.22	0.4	100.00
1990										
10^8 Yuan	70.42	32.83	334.33	288.09	94.35	59.76	3.43	1.52	3.16	887.89
%	7.93	3.70	37.65	32.45	10.63	6.73	0.39	0.17	0.36	100.00
2000										
10^8 Yuan	67.93	44.01	455.69	305.78	89.27	62.93	2.81	1.54	3.88	1,033.84
%	6.57	4.26	44.08	29.58	8.63	6.09	0.27	0.15	0.38	100.00
2005										
10^8 Yuan	83.96	55.79	347.06	365.18	110.27	84.74	7.49	3.44	4.65	1,062.57
%	7.90	5.25	32.66	34.37	10.38	7.98	0.70	0.32	0.44	100.00
1985–1990										
10^8 Yuan	−14.96	−24.06	−103.60	−54.85	1.05	−8.09	−2.01	−0.85	−1.26	−208.63
%	−17.52	−42.30	−23.66	−15.99	1.12	−11.93	−36.90	−35.82	−28.55	−19.03
%/year	−3.50	−8.46	−4.73	−3.20	0.22	−2.39	−7.38	−7.16	−5.71	−3.81
1990–2000										
10^8 Yuan	−2.49	11.19	121.37	17.69	−5.09	3.17	−0.63	0.02	0.73	145.95
%	−3.54	34.08	36.30	6.14	−5.39	5.31	−18.32	1.43	22.97	16.44
%/year	−0.35	3.41	3.63	0.61	−0.54	0.53	−1.83	0.14	2.30	1.64
2000–2005										
10^8 Yuan	16.03	11.78	−108.64	59.40	21.00	21.81	4.68	1.90	0.77	28.73
%	23.59	26.76	−23.84	19.42	23.53	34.66	166.88	123.48	19.80	2.78
%/year	4.72	5.35	−4.77	3.88	4.71	6.93	33.38	24.70	3.96	0.56
1985–2005										
10^8 Yuan	−1.42	−1.10	−90.87	22.24	16.96	16.89	2.04	1.07	0.23	−33.95
%	−1.66	−1.93	−20.75	6.49	18.18	24.89	37.54	45.48	5.26	−3.10
%/year	−0.08	−0.10	−1.04	0.32	0.91	1.24	1.88	2.27	0.26	−0.15

The contribution of each ecosystem service to ESVs had been quite stable during the last 20 years. The rank of single ESV from high to low was as follows: nutrient cycling, organic production, soil formation and gas regulation, biodiversity, soil reservation, water conservation, and recreation and culture (Table 3). Nutrient cycling, organic production, soil formation and gas regulation were the most important part of ESVs. They were calculated at 72.69, 64.57, 70.18 and 72.10% of total ESVs in 1985, 1990, 2000 and 2005, respectively. The ESVs of recreation and culture, water conservation and soil reservation remained quite low, and each of them was below 10 billion Yuan (17.44, 23.82, 19.26 and 24.76% of total ESVs, respectively, in the 4 years) (Table 3). For example, the ESVs of recreation and culture were only 5.134 billion Yuan in 1985, 4.861 billion Yuan in 1990, 4.929 billion Yuan in 2000, and 5.376 billion Yuan in 2005. Only the rank of gas regulation and soil reservation decreased, and the rank of water conservation and soil formation increased. The rank change of gas regulation and soil reservation was from 3 to 4 and from 6 to 7, respectively. The rank change of water conservation and soil formation was from 7 to 6 and from 4 to 3, respectively.

Spatial Distribution of ESVs

With regards to spatial distribution of ESVs a trend of decline was observed from the west to the east of the study area (Fig. 2). ESVs in the west were higher due mainly to the fact that vegetation coverage is much higher and denser for this part of the region. The average ESVs were more than 15,000 RMB Yuan/ha in the west which also acts as the main natural reserve for endangered wildlife species in Guangxi (Fig. 1). This area is also considered one of the best preserved natural vegetation regions in China. The ESVs were less than 10,000 Yuan/ha in the middle part of the region due to low vegetation coverage and the serious karst rocky desertification. These observations are similar

Table 3 Rank of single ecosystem service values (ESVs) in Northwest Guangxi, China

	1985			1990			2000			2005			Overall rank	Tendency
	ESV (10^8 Yuan)	%	Rank	ESV (10^8 Yuan)	%	Rank	ESV (10^8 Yuan)	%	Rank	ESV (10^8 Yuan)	%	Rank		
Gas regulation	180.40	16.45	3	114.70	12.92	4	153.49	14.85	4	173.12	16.29	4	4	↓
Water conservation	70.01	6.38	7	77.34	8.71	7	68.32	6.61	7	70.01	6.59	6	6	↑
Soil reservation	70.01	6.38	6	85.55	9.64	6	81.42	7.88	6	69.34	13.11	7	7	↓
Organic production	184.85	16.86	2	117.53	13.24	3	163.66	15.83	3	177.39	16.69	2	2	–
Nutrient cycling	256.96	23.43	1	172.20	19.39	1	233.46	22.58	1	240.77	22.66	1	1	–
Soil formation	174.95	15.95	4	168.91	19.02	2	174.95	16.92	2	174.95	16.46	3	3	↑
Biodiversity	108.00	9.85	5	103.05	11.61	5	109.25	10.57	5	103.24	9.72	5	5	–
Recreation and culture	51.34	4.68	8	48.61	5.47	8	49.29	4.77	8	53.76	5.06	8	8	–
Total	1,096.52	100	–	887.89	100	–	1,033.84	100	–	1,062.57	100	–	–	–

The contribution shifts are presented by an upward arrow "↑" for increasing contribution, downward arrow "↓" for decrease in contribution, and a dash "–" for no change

to what has been reported in previous studies. Specifically, rocky desertification mainly occurs in the middle, 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 eastern part of this study region. The results indicate that the environment has a strong impact on the ESVs in this study region.

Spatial variations of ESVs were different from the spatial distribution of ESVs (Fig. 3). ESVs have decreased in the entire region from 1985 to 1990. This indicates severe degradation of karst ecosystems during this period. The ESVs then increased, mostly in the northern part of the study area, from 1990 to 2000 due to LULC conversion. ESVs had also increased in the northwest portion while decreasing in the southeast from 2000 to 2005. From 1985 to 2005, ecosystem conditions did improve and the ESVs increased in the middle and eastern part of this study region. Nevertheless, the decrease of ESVs in most places in western portion of the study area indicates that ecosystem conditions had worsened in some areas. The overall improvement of ESVs more recently may be attributed to shift in policies of forest harvesting in the 1990s, the ecological migrants and the Green for Grain program in the twenty-first century. In the 1990s large scale timber harvesting in Guangxi occurred for improved economic benefit. With the ever increasing environment protection consciousness, governments at different levels initiated the Green for Grain program soon after (Yang 2003). In summary, the ecosystem services have improved in most middle and eastern parts of this study region as the result of recent implementations of control measures for dealing with rocky desertification. In contrast, most regions in the western section of this study area, which represents most of the tropical rain forests and subtropical evergreen broad-leaved forests, have become worse.

Relationship Between ESVs and EFs

There are significant correlations between ESVs and EFs. The correlation coefficient of the first and second axis of the ESVs matrix and that of environmental matrix was 0.81 and 0.80, respectively ($P = 0.01$). The first two axes explain 82.6% of variation of ESVs matrix, with 93.3% of the relationship between ESVs and environmental variables (Table 4). This result indicates that most correlation information focus on the first two axes. The environmental variables are represented by various line segments in the graph. The relationship between the EFs and the ESVs could be examined through the length of the line segments and the angle between these line segments and the axes. The longer the line, the stronger the influences it has on the

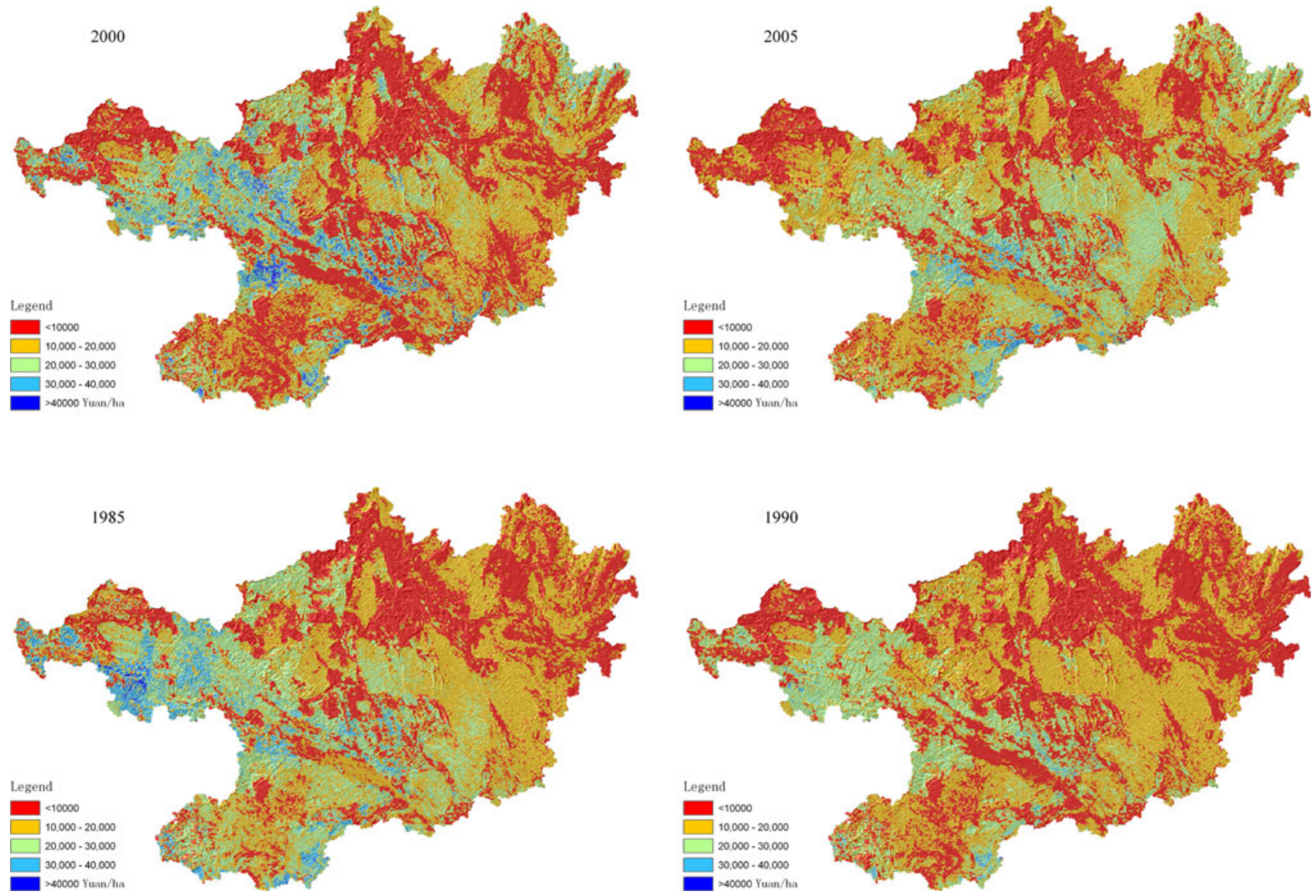


Fig. 2 Spatiotemporal distributions of ecosystem service values (ESVs) in Northwest Guangxi, China from 1985 to 2005

ESVs. Moreover, the smaller the angle between the variable and the axes in the diagram the larger the correlation coefficient.

In Fig. 4a, axis 1 is highly correlated with slope, rock types, cultivated land per capita and annual rainfall. The first axis increases with slope and annual rainfall and decreases with cultivated land per capita and rock types. The second axis increases with elevation and decreases with vegetation types. Elevation, slope and vegetation coverage increase whereas annual rainfall decrease when the axis 1 increases. Consequently, the upper part in the ordination represents areas with high elevation and slope. ESVs of nutrient cycling and organic production are in close relationships with soil types and vegetation coverage. High nutrient cycling and organic production mainly occur in places with fertile soil and high vegetation coverage. ESVs of soil formation and water conservation are closely related to annual rainfall and vegetation types and are affected mainly by rainfall. ESVs of biodiversity and gas regulation are in close relationship with cultivated land per capita. ESVs of soil reservation are highly correlated with slope and elevation and forest and grassland are typically at higher elevations. It is uncommon to find them in low elevations due to strong human disturbances. In contrast, ESVs of recreation and culture are slightly influenced by natural factors such as topography and more influenced by towns and roads.

In Fig. 4b, axis 1 is correlated with the counties that are known for desertification such as Tianyang, Baise, Nandan, Lingyun and Du'an (Fig. 4). Most of the remaining counties have lower correlation with the EFs. Furthermore, the impacts of EFs on ESVs are different between the counties. For example, vegetation types and annual rainfall are more important for ESVs for Hechi and Yizhou, while elevation and slope are more important for ESVs in Napo, Debao and Leye counties. Consequently, more attention should be paid to vegetation protection in Hechi and Yizhou counties. Policies regarding the reclamation of cropland in the low elevation such as poljes with high slope angles could also be applied more strictly in the counties of Napo, Debao and Leye.

Discussion

Compared with other study areas in China (Chen and Zhang 2000; Pan and others 2004; Wang and others 2007;

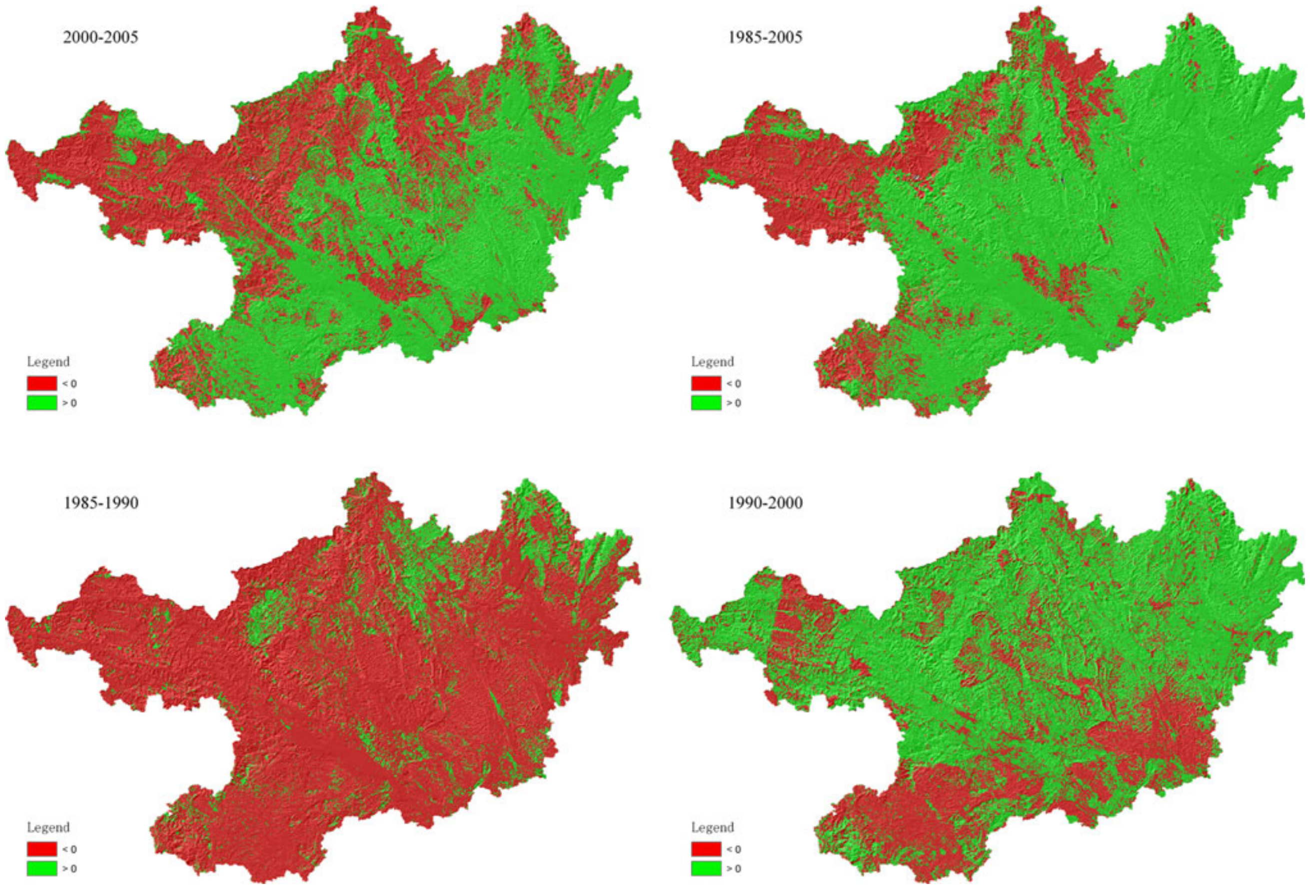


Fig. 3 Spatiotemporal variations of ecosystem service values (ESVs) in Northwest Guangxi, China from 1985 to 2005

Table 4 Correlation coefficients for ecosystem service values (ESVs) and environmental factors (EFs)

	SPX1	SPX2	ENX1	ENX2	DEM	SL	CLPC	AR	RT	ST	LT
SPX2	0.10										
ENX1	0.81**	0.00									
ENX2	0.00	0.80**	0.00								
DEM	−0.22	0.58*	−0.28	0.72**							
SL	−0.61**	0.42*	−0.75**	0.53*	0.64**						
CLPC	0.15	0.52*	0.18	0.65**	0.45*	0.23					
AR	−0.40*	−0.47*	−0.50*	−0.59*	−0.17	0.20	−0.59**				
RT	0.19	0.25	0.24	0.31	0.27	0.21	0.20	−0.48*			
ST	0.05	0.37	0.06	0.46*	0.45*	0.33	0.40	−0.51*	0.81**		
LT	−0.14	−0.52*	−0.18	−0.65**	−0.30	−0.39	−0.13	0.13	−0.34	−0.32	
VC	0.03	0.24	0.03	0.30	0.13	0.27	0.42*	−0.39	0.65**	0.62**	−0.28

SPX1 and SPX2 is respectively the first and second axis of ecosystem service values (ESVs), ENX1 and ENX2 is respectively the first and second axis of environment factors (EFs)

DEM elevation, *SL* slope, *CLPC* cultivated land of per capita, *AR* annual rainfall, *RT* rocky types, *ST* soil types, *LT* vegetation types, *VC* vegetation coverage

* $P = 0.05$, ** $P = 0.01$

Li and others 2008), the per unit area ESVs in Guangxi were fairly high due primarily to a longer growing season, high temperatures, ample precipitation and the dominance of mixed woodland (Table 5). According to Pan and others (2004), the ESVs of Guangxi in 2000 were 601.5505 billion Yuan (ranked seventh among all the 34 provinces in China). However, the per unit area ESVs in this study area were lower because of the widespread bedrock and rocky

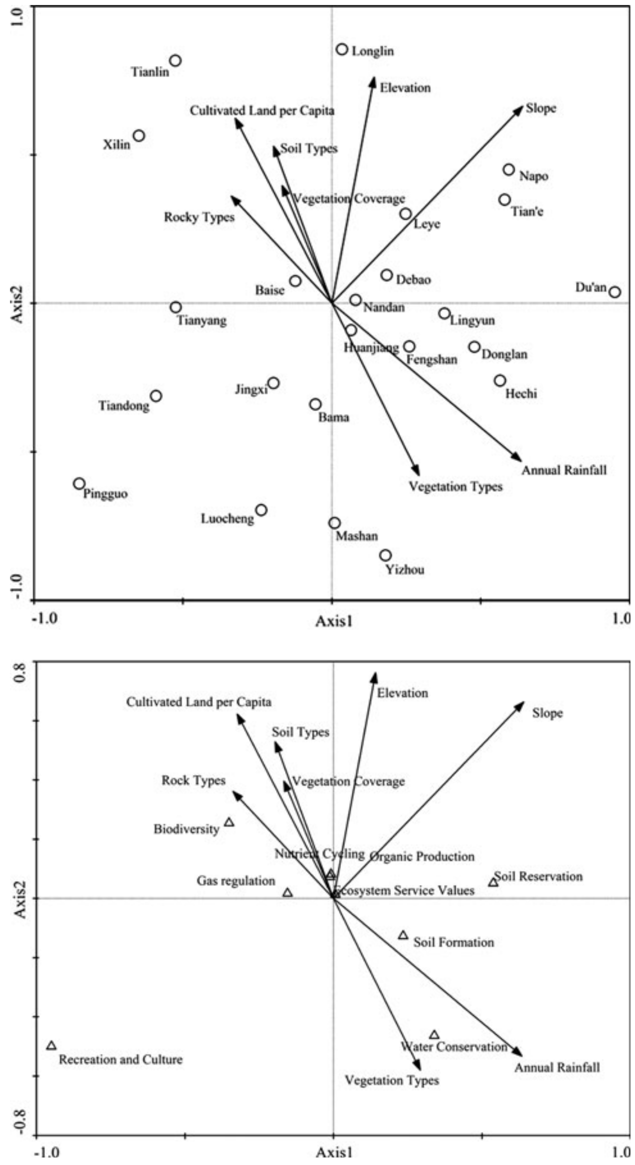


Fig. 4 The relationship between ecosystem service values (ESVs) and environmental factors (EFs) in Northwest Guangxi, China, where the length of vector expresses the intensity of EFs impacting on ESVs, and the direction of arrowhead expresses the relation of EFs and ESVs

desertification. NW Guangxi is about 30.41% of Guangxi in area, while its ESVs were only 17.19% of those of Guangxi. ESVs in typical karst areas were low and had increased (14,273.11 Yuan/ha in 1985 and 15,169.29 Yuan/ha in 2005). The ecosystem conditions may have improved due to the implementation of policies dealing with rocky desertification in those areas of rocky desertification identified during the 1985–2005 period. The focus of one campaign, environmental migration, was to help farmers in karst areas move to non karst areas where ecosystem conditions were deemed much better in the 1990s. 49,133 families (232,705 persons) were relocated during this campaign in NW Guangxi, China. The total area of conversion from farmland to woodland was also up to 1,278.67 km^2 in Baise in 2001–2004. This included 605.33 km^2 of farmland returning to woodland and 673.33 km^2 of reforestation activities of barren hills.

Results from the CCA indicate that the impact of slope on ESVs is significant and negative. The percentage of bare rock in the study area is higher above the middle of a slope and that this is generally corresponding to a higher degree of karst rocky desertification (Zhang and others 2004, 2007). The results also show that per capita cropland has a positive correlation to ESVs because the crop land, converted from scattered woodland especially for the orchard, enhanced the ESVs. The results of this study also indicate that the land use policy and the environmental migration policy were the main driving forces that have influenced how farmers adapted to land use and subsequently modified the landscape patterns which have influenced the ESVs in the study regions. To control karst rocky desertification and to improve the farmer's living conditions, it is suggested that the land use structure in 2005 was better and more acceptable than for those in 1985 and 1990.

The conflict between economical development and environmental protection is a common issue Worldwide and it is no different for the situation of rocky desertification in karst areas (Zhao and others 2004; Brown and others 2010). It is clear that poor environmental quality is an important precondition in this karst area. Therefore,

Table 5 Per unit area ecosystem service values (ESVs) of different regions in China

Name	Per unit area ESV (Yuan/km^2)	Latitude	Climate	Main LULC
Northwest Guangxi	1,436,048.4	23°41′–25°37′N	Subtropical monsoon climate	Mixed woodland
Guangxi	2,541,404.7	20°54′–26°20′N	Sub-tropical monsoon climate	Mixed woodland
Pingbian County	421,406.1	22°49′–23°28′N	Tropical rain forest climate	Crop
Inner Mongolia	530,287.4	37°24′–53°23′N	Temperate monsoon climate	Grass
Shenzhen	125,970.3	22°27′–22°52′N	Mild, subtropical maritime climate	Urban
China	468,812.5	3°51′–53°31′N	Continental monsoon climate	Mixed woodland; urban; grass

conservation of karst areas and their ecosystems should take precedence over the uncontrolled reclamation of these areas for economic purposes in future land use practice. While it may not be feasible to stop all reclamation activities in this area, it is imperative that future land-reclamation projects be controlled and based on rigorous environmental impact analyses. To achieve this, more detailed studies of the impacts of karst reclamation projects on the ecosystem services provided in the southwest China are necessary.

This investigation also evaluated the spatiotemporal variations in karst areas based on previous research and field verification. However, these estimated results are quite coarse in resolution due to the complex and dynamic ecosystems themselves (Limburg and others 2002; Li and others 2010) and due to problems of scales (Hein and others 2006). Consequently, ecosystem types might not perfectly match LULC types in every case (Kreuter and others 2001; Zhao and others 2010) though they were modified by the NPP and vegetation coverage in this study. A multi-scale assessment of ESVs is necessary, because ecosystem goods and services play an ecological system security, and represent the final product of a wide range of conditions and processes (Petrosillo and others 2009). Another important factor which should be taken into account in future ecosystem service valuation is spatial scale. The spatial scale at which the LULC is measured significantly influences measurements of both the ecosystem service extent and its valuation (Konarska and others 2002). Compared with other ecosystems, karst ecosystem areas are much more fragile and heterogeneous. Consequently, the spatial scale and resolution of measurement are important factors which should be taken into account in future ecosystem service valuations of this or similar regions.

Conclusion

Results from this study showed that shrub, woodland, scattered woodland and grassland were the dominant LULC types. From 1985 to 2005, the speed of deforestation was slowed down and was replaced by grassland restoration and reforestation. The total ESVs decreased from 109.652 billion to 88.789 billion and then increased. However, the ESVs of 2005 were less than those of 1985. ESVs were estimated at about 109.652 billion Yuan, 88.789 billion Yuan, 103.384 billion Yuan, and 106.257 billion Yuan in 1985, 1990, 2000, and 2005, respectively. The unit area of ESVs was relatively low compared with other regions which might be explained through the widely distributed rocky desertification in the study area. Regarding the contribution from various ecosystem functions, the ESVs from nutrient cycling, organic production and gas regulation were high and the ecosystem services of water conservation, soil reservation and recreation and culture were relatively low. Moreover, the ESVs declined from the west to the east and the results of the CCA showed that the most important factors influencing ESVs are slope, annual rainfall, vegetation coverage and per capita cropland. The results of this study also indicates that ecosystem conditions in typical karst areas have been improved because of the application of rocky desertification control policies, such as ecological migration and the Green for Grain program.

Acknowledgments This study was supported by the Chinese Academy of Sciences Action Plan for the Development of Western China (KZCX2-XB3-10), National Natural Science Foundation of China (31000223, 41071340), the Western Light Program of Talent Cultivation of the Chinese Academy of Sciences, the Knowledge Innovation Program of the Chinese Academy of Sciences (ISACX-LYQY-QN-1102). We gratefully acknowledge Dr. J.M. Kovacs' (Nipissing University, Canada) constructive suggestions as well as his editing of the manuscript. We would also like to thank the anonymous reviewers' help with the improvement of this manuscript.

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