

An assessment of conservation effects in Shilin Karst of South China Karst

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Abstract World Heritage is of outstanding universal value and has irreplaceable sources of life and inspiration to humanity. It is important to evaluate the effectiveness of World Heritage site management. As a part of the South China Karst World Natural Heritage, Yunnan Shilin Karst was included in the World Heritage list on 27 June 2007. To quantify the effects of the Yunnan Shilin Karst site conservation, the changes in ecosystem service value of the Yunnan Shilin Karst area and the nearby buffer zone were analyzed by utilizing remote-sensing images, geographic information system and an ecosystem service value model. The results indicate that significant conservation effects of the Yunnan Shilin Karst have been made since 1992, and of the buffer zone since 2004.

Keywords Ecosystem service value · Conservation effects · Geographic information system (GIS) · World Heritage · Buffer zone · Shilin Karst

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Introduction

World Heritage is of outstanding universal value and has irreplaceable sources of life and inspiration to humanity (UNESCO World Heritage Centre 2010a). Conservation and management of World Heritage properties should maintain or enhance the outstanding universal value and the conditions of integrity and/or authenticity at the time of inscription for the future (UNESCO World Heritage Centre 2008). There are a growing number of studies on the topic of World Heritage conservation (Davis and Weiler 1992; Ross et al. 1995; Davies et al. 2007; Hazen 2008; Pendlebury et al. 2009).

Valuing ecosystem services is considered as an effective tool for quantifying benefits of natural ecosystems (Costanza et al. 1997; Daily 1997; Heal 2000; Kreuter et al. 2001; Costanza and Farber 2002; de Groot et al. 2002; Millennium Ecosystem Assessment 2005). Ecosystem services are defined as the conditions and processes through which natural ecosystems and the species that comprise them sustain and fulfill human life (Daily 1997). The use of remote-sensing images makes data collection much more easily available than before and has become an important tool for acquiring environmental data at spatial, temporal and spectral resolutions, appropriate for assessing broad land use changes (Verstraete et al. 1996; Kreuter et al. 2001; Konarska et al. 2002; Sutton and Costanza 2002; Huang et al. 2010). The use of geographic information systems (GIS) enables easier and more accurate evaluation of ecosystem services (Troy and Wilson 2006; Grêt-Regamey et al. 2008; Chen et al. 2009; Raymond et al. 2009; Tianhong et al. 2010). Remote-sensing images and GIS are also considered to be the best technical tools for temporal and spatial collecting and processing of place-specific information.

For evaluating the conservation effects, the ecosystem service approaches are proposed to engage a much wider range of places, people, policies, and financial resources in conservation. This is particularly important given the projected intensification of human impacts, with rapid growth in population size and individual aspirations (Goldman et al. 2008).

There are three issues which have the potential to affect the integrity of the ecosystems of the Yunnan Shilin Karst: (1) downstream effects of upstream runoff; (2) local human impact; and (3) increased tourism (IUCN 2007). The local government spends a lot of manpower, materials and financial resources in World Heritage protection. Such protection effects, however, are seldom taken into consideration in decision-making. Up to now, what has happened in the Yunnan Shilin Karst, from the time of first nomination to the final inclusion in the World Heritage List, and what is the progress in ecological restoration? How do we carry out such an assessment? The aims of this study are: (1) to analyze the transition among ecosystem types since the nomination of the Shilin Karst for inclusion in the World Heritage List; (2) to evaluate its ecosystem service value and change; and (3) to illustrate the spatial distribution of ecosystem service value with useful information for decision-making for better conservation.

Materials and methods

Study area

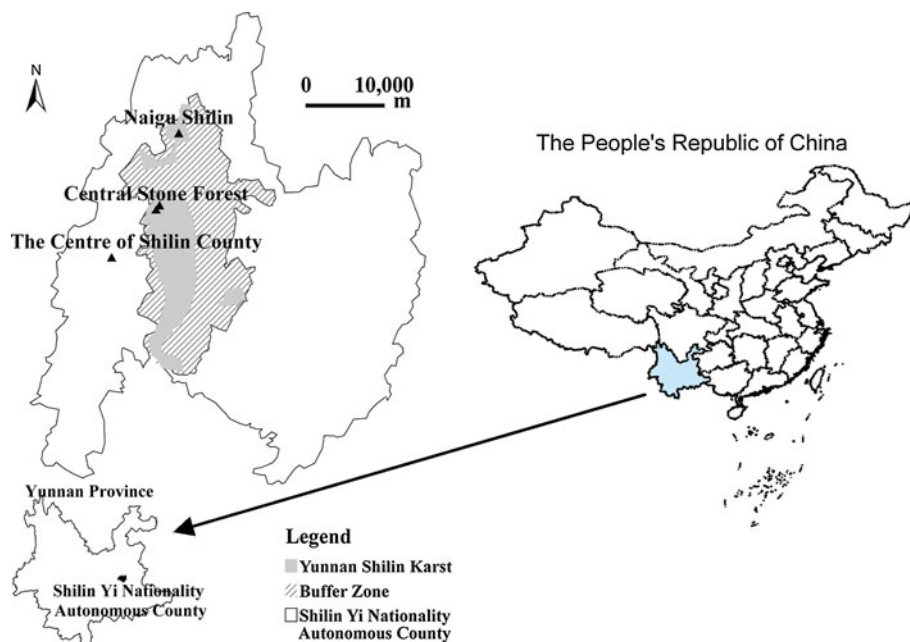
The Yunnan Shilin Karst, a part of the South China Karst World Heritage, was included in the World Heritage List

on 27 June 2007. It is located in the Shilin Yi Nationality Autonomous County, Kunming, Yunnan Province of southwest China, stretching between longitudes 103°11' E and 103°29' E and latitudes 24°38' N and 24°58' N with elevations from 1,600 to 2,203 m. The Yunnan Shilin Karst World Heritage includes two sites: Naigu Shilin and the Central Stone Forest. The Yunnan Shilin Karst covers 12,000 ha and the buffer zone covers 23,000 ha (Fig. 1). It has a subtropical monsoon climate. The average annual precipitation is 967.9 mm (42 years) and the average maximum temperature is 20.8 °C in July and the average minimum is 8.2 °C in January.

Human activities in the Shilin Karst and the buffer zone are intensive. There are 5 villages in the Shilin Karst and 30 villages in the buffer zone. From 1992 to 2007, the population of the Shilin Karst grew from 4,180 to 4,713 at an increasing rate of 8.50 ‰, while the population in the buffer zone increased from 25,271 to 29,053 at an increasing rate of 9.98 ‰ (data from 1993 to 2008, Shilin Yi Nationality Autonomous County Statistics Data, and the First National Agricultural Census of Shilin Yi Nationality Autonomous County in 2001).

The Shilin Karst consists of stone forests with a wide diversity of closely spaced pinnacles and towers, with examples of “stone forest” karst landscapes noted for high limestone pinnacles and towers, marked by deep and sharp karren. The Shilin Karst also illustrates the episodic nature of the evolution of these karst features spanning 270 million years (IUCN 2007). The stone forests of Shilin are considered as outstanding natural phenomena and a world reference site for this type of feature (UNESCO World Heritage Centre

Fig. 1 Location of the study region



2010b). The Shilin Yi Nationality Autonomous County encountered many difficulties in including it in the World Heritage List. In 1991, the Shilin Karst was first nominated to the World Heritage List by China, but was not accepted at the 16th session of the World Heritage Committee in Santa Fe in 1992 because of some deficiencies, such as lack of comparative analysis and deficiencies in the demonstration of the outstanding universal value of the site, as well as the evident human disturbance which has resulted in a significant loss of biological value (IUCN 2007). Since then, the local government has done much, both in studying the stone forest and improving the management of the sites, for example, organizing a comprehensive study of the Karst from 1992 to 1997, revising the Master Plan of the Stone Forest National Scenic and Historical areas in 2001, and restoration and replanting of natural vegetation. These measures have produced good effects. The Shilin Karst joined China National Geopark network in 2001, and was inscribed into the UNESCO Geoparks in 2004. In 2007, The Yunnan Shilin Karst was accepted as a part of South China Karst World Heritage by the World Heritage Committee.

Data

Considering the management stages of the Stone Forest National Scenic and Historical Areas in the process of the nomination for World Heritage, the conservation effects in 1992, 2004 and 2009 were evaluated by analyzing the changes in ecosystem service value from 1992 to 2004 and 2004 to 2009 using GIS, the Landsat TM image in 1992, SPOT image in 2004, and ALOS image in 2009 on the basis of the ecosystem service model. The remote-sensing images were processed by the use of ERDAS (V8.5). The images were classified on the basis of the land use map of the Shilin Yi Nationality Autonomous County in 1992 and the status protection zoning map of the Shilin Karst in 2002, by means of supervised classification and visual interpretation into seven ecosystem types, including cropland, woodland, grassland, built-up areas, water areas, stone forests and unexploited land (Table 1). Mapping and analysis of ecosystem service value were based on the remote-sensing images and processed by the use of ArcGIS (V9.2) (ESRI Inc.). The statistical data were obtained from the Shilin Yi Nationality Autonomous County Statistics Data from 1993 to 2008 and the First National Agricultural Census of Shilin Yi Nationality Autonomous County in 2001.

Methods

Change rate of ecosystem types

A change rate of single-type ecosystem shows the quantified change of one type of ecosystem conditions in the

Table 1 Ecosystem types in the Shilin Karst and the buffer zone

Ecosystem types	Definition
Cropland	Paddy field, non-irrigated farmland and irrigated land
Woodland	Orchard, arbor, bamboo, bush forest and forest along the roads and railways
Grassland	Natural grassland and manmade grassland
Built-up areas	Land used for industrial, commercial, residential and transportation purposes
Water areas	Rivers, reservoirs, fishery and lakes
Stone forests	Karst landscapes with pinnacles
Unexploited land	Lands unused or resistant to use

study area during a period of time. It is expressed as the following (Liu and Buheaozier 2000):

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100 \% \tag{1}$$

where K is the change rate of one type of ecosystem conditions in the study period; U_a and U_b are the areas of one type of ecosystem at the beginning and the end of the study period, respectively; T is the years of the study period.

Valuation methods

An ecosystem service valuation model was developed on the basis of Costanza et al. (1997). The model is expressed as follows:

$$V = \sum_{i=1}^m \sum_{j=1}^n P_{ij} \times A_i \tag{2}$$

where V is the total value of ecosystem service in the study area; P_{ij} is the j -th ecosystem service value per unit area of the i -th ecosystem type; A_i is the area of the i -th ecosystem type in the study area; m is the number of ecosystem types in the study area; n is the number of ecosystem services being valued.

The ecosystem service value was calculated with the ecosystem service valuation methods (Table 2).

In the Shilin Karst and its buffer zone, the effects of protection and management were quantified through the valuation of the ecosystem service of woodland, grassland, water areas and stone forests, because these ecosystems are natural ecosystems that could best reflect the ecological conditions. In addition, cropland, built-up areas and unexploited land were considered as the ecosystems that were imposed on the natural ones by human pressure.

Table 2 Ecosystem service valuation methods

Items	Methods
Provisioning	
Food production	Market price
Raw material	Market price
Regulating	
Climate regulation	Contingent valuation
Gas regulation	Market price, carbon tax
Water regulation	Water balance rule, shadow project
Air purification	Market price
Waste disposal	Shadow project
Supporting	
Nutrient cycling	Market price
Soil formation and retention	Market price
Biodiversity protection	Benefit transfer
Cultural	
Recreation and culture	Travel cost

Woodland ecosystem service valuation

1. Climate regulation

Forests can change the local temperature, cloud cover and precipitation. The contingent valuation method was adopted to calculate the climate regulation service. Xie et al. (2003) estimated the value of climate regulation service. The value of the climate regulation service per hectare is 2,389.10 Yuan/ha.

2. Gas regulation

The function of gas regulation is the greenhouse gas storage/emission and oxygen production. According to the formula of photosynthesis and respiration, when woodland ecosystem absorbs 1 g of CO₂, it releases 0.73 g of O₂. The economic value of greenhouse gas storage/emission was calculated by using the methods of market price and carbon tax (Ouyang et al. 1999; Zhao et al. 2004). A 1:8 USD–RMB exchange rate was adopted. In this study, the average of the results of these two methods, 28,211.41 Yuan/ha, was the value of gas regulation per hectare.

3. Water regulation

The function of water regulation is to provide flood control ability and water recovery for the drought period. Water balance rule and the shadow project method were adopted to evaluate the water regulation value (Huang et al. 1993, 1998; Li 1999; Zhao et al. 2000, 2004; Yu et al. 2002). The valuation model is:

$$V_{wr} = A \times J \times R \quad (3)$$

where V_{wr} is the water regulation value; A is the area of the woodland; J is the average rainfall runoff of the study area;

R is the effectiveness coefficient by which the woodland ecosystem could reduce the runoff compared to the bare land.

4. Air purification

Air purification involves absorption of pollutants (e.g., SO₂, HF, NO_x) and reduction of dust. The market price method was adopted to evaluate the air purification value. The valuation model is:

$$V_{ap} = Q_a \times C_p + Q_b \times C_d \quad (4)$$

where V_{ap} is the air purification value; Q_a is the weight of pollutant absorption per hectare of woodland; C_p is the cost which reduces pollutants per kilogram; Q_b is the weight of block dusts per hectare of woodland; C_d is the cost which blocks dust per kilogram. The data were from the Editorial Committee of State Report on Biodiversity of China Committee (1997).

5. Nutrient cycling

Nutrient cycling refers to the circulation of nitrogen, phosphorus, potassium and organic matter. The study by Mo et al. (2000) shows that in the subtropical evergreen broad-leaved forest, the proportion of nitrogen in plants was 0.826 %, phosphorus 0.035 % and potassium 0.633 %, and the net primary productivity was 17.27 t/ha. We take the average of the proportion of nitrogen, phosphorus and potassium and adopt the market price method to evaluate the nutrient cycling value (National Bureau of Statistics of China 1992; Mo et al. 2000).

6. Soil formation and retention

The market price method was adopted to evaluate the soil formation and retention values. The valuation models are as follows:

$$V_{nc} = E_f + E_s + E_n \quad (5)$$

$$A_c = A_r - A_g \quad (6)$$

$$E_f = \sum A_c \times S_i \times P_i \quad (i = N, P, K) \quad (7)$$

$$E_s = \frac{A_c \times B}{0.6p} \quad (8)$$

$$E_n = A_c \times 24 \% \times C \div p \quad (9)$$

where V_{nc} is the nutrient cycling value; E_f is the value for reducing the loss of soil fertility; E_s is the value for reducing soil erosion; E_n is the value for reducing sediment deposition; A_c is the volume of soil conservation; A_r is the volume of soil erosion in non-forest ecosystems; A_g is the volume of soil erosion in forest ecosystem; S is the average soil nutrient content; P is the average price of nutrients; B is the average efficiency of forestry production; p is soil bulk density; C is reservoir project costs. The data were from: National Bureau of Statistics of China (1992); Editorial Committee of State Report

on Biodiversity of China Committee (1997); Ouyang et al. (1999); Xue et al. (1999); Yu et al. (2002) and Lu et al. (2006).

7. Biodiversity protection

The function of biodiversity protection refers to the environment that provides vegetation and animals to the habitat and refuges to preserve biodiversity of the ecosystem. The benefit transfer method was adopted to evaluate the biodiversity protection value. Xie et al. (2003) estimated the biodiversity protection value. The value of biodiversity protection per hectare is 2,884.60 Yuan/ha.

8. Recreation and culture

Recreation and culture reflect the esthetic and scientific value the ecosystem provides. The travel cost method was adopted to evaluate the recreation and culture value. The value proposed by Xie et al. (2003), 1,132.60 Yuan/ha, was adopted as the recreation and culture value per hectare.

Grassland, water areas and stone forests ecosystem service valuation

Based on the ecosystem service value per unit area of Chinese terrestrial ecosystems in Xie et al. (2003), one factor is equal to the economic value of average natural food production of cropland per hectare per year. Generally, the economic value provided by the natural ecosystem without labor input is 1/7 of the economic value of grain production per current unit area of the actual food production (Xiao et al. 2003). Considering the specific conditions of the study area, the average grain production of Shilin Yi Nationality Autonomous County from the year 1992 to 2007 (4,599 kg/ha) was taken as the food production of the cropland of the study area, and the average price for grain of the Shilin County in 2007 was 1.48 Yuan/kg. Therefore, the ecosystem service value of one equivalent weight factor for the study area was 972.36 Yuan. On the basis of this modified criterion, the ecosystem service value per unit area of grassland and water area were calculated. In the Shilin Karst, the functions of the stone forest's ecosystem are mainly recreation and culture functions, and therefore, the highest value in the recreation and culture functions in Xie et al. (2003) was adopted. The desert ecosystem service value per unite area in Xie et al. (2003) was used as the other ecosystem service value per unit area of stone forests except recreation and culture functions.

Results

Change in area of ecosystem types

There were big changes in area of the ecosystem types, both in the Shilin Karst and the buffer zone from 1992 to

2009 (Figs. 2, 3). In the Shilin Karst, cropland and woodland increased, while grassland, stone forests and unexploited land decreased; built-up areas increased from 1992 to 2004 and decreased from 2004 to 2009; water areas decreased from 1992 to 2004 and increased from 2004 to 2009. In the buffer zone, cropland increased, while unexploited land decreased. Woodland and grassland decreased from 1992 to 2004 and increased from 2004 to 2009; built-up areas, water areas and stone forests increased from 1992 to 2004 and decreased from 2004 to 2009.

Transition among ecosystem types

The transition features of the ecosystems in areas in the Shilin Karst for 1992–2004 and 2004–2009 are presented in Table 3. The transition features of ecosystems in areas in the buffer zone in the same periods are given in Table 4.

The results of the ecosystems in area transition matrix showed that between 1992 and 2004 in the Shilin Karst, the main part of the increased area of cropland was from grassland (142.19 ha) and unexploited land (95.90 ha). Most of the increased area of woodland was from grassland (769.12 ha), unexploited land (97.17 ha) and cropland (92.66 ha). Most of the increased area of built-up areas was from grassland (2,053.82 ha) and unexploited land (78.42 ha).

Between 2004 and 2009 in the Shilin Karst, most of the decreased area of built-up areas was transformed into grassland (1,541.65 ha) and unexploited land (269.53 ha). Most of the increased water areas were from built-up areas (65.10 ha).

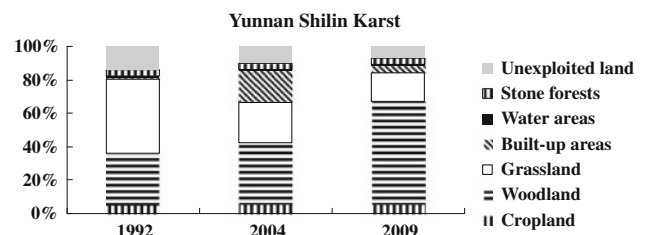


Fig. 2 Proportion of ecosystem types' area in the Yunnan Shilin Karst

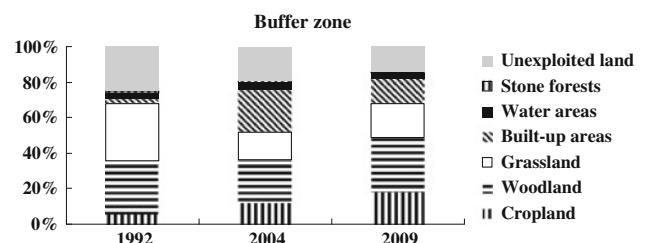


Fig. 3 Proportion of ecosystem types' area in the buffer zone

Table 3 Transition matrix of ecosystem types from 1992 to 2009 in the Shilin Karst (ha)

	C	W	G	B	Wa	S	U	Total in 1992
1992–2004								
C	456.91	92.66	80.43	0	0	0	0	630
W	0	3,407.14	292.86	0	0	0	0	3,700
G	142.19	769.12	2,327.87	2,053.82	0	0	0	5,293
B	0	0	4.98	116.76	4.43	0	33.83	160
Wa	0	9.91	27.11	0	46.98	0	0	84
S	0	0	5.38	0	2.62	451.00	0	459
U	95.90	97.17	194.37	78.42	1.97	0	1,206.17	1,674
Total in 2004	695	4,376	2,933	2,249	56	451	1,240	12,000
	C	W	G	B	Wa	S	U	Total in 2004
2004–2009								
C	546.57	48.20	100.23	0	0	0	0	695
W	0	4,221.94	154.06	0	0	0	0	4,376
G	92.19	2,632.27	98.31	110.23	0	0	0	2,933
B	0	0	1,541.65	372.72	65.10	0	269.53	2,249
Wa	0	8.18	3.20	0	44.62	0	0	56
S	0	0	0.36	0	0.64	450.00	0	451
U	59.24	446.41	168.19	30.05	0.64	0	535.47	1,240
Total in 2009	698	7,357	2,066	513	111	450	805	12,000

C cropland, W woodland, G grassland, B for built-up areas, Wa water areas, S stone forests and U unexploited land

Table 4 Transition matrix of ecosystem types between 1992 and 2009 in the buffer zone (ha)

	C	W	G	B	Wa	S	U	Total in 1992
1992–2004								
C	1,091.29	245.66	33.05	0	0	0	0	1,370
W	1,200.77	4,588.69	1,060.54	0	0	0	0	6,850
G	285.55	89.80	383.64	4,269.56	398.73	0	1,929.72	7,357
B	0	0	6.47	730.82	2.71	0	0	740
Wa	0	0	56.60	129.07	530.33	0	0	716
S	0	0	0	0	0	174.00	0	174
U	327.39	499.85	2,027.70	420.55	12.23	11.00	2,494.28	5,793
Total in 2004	2,905	5,424	3,568	5,550	944	185	4,424	23,000
	C	W	G	B	Wa	S	U	Total in 2004
2004–2009								
C	1,240.90	733.77	930.33	0	0	0	0	2,905
W	0	4,989.49	434.51	0	0	0	0	5,424
G	2,285.41	331.96	950.63	0	0	0	0	3,568
B	0	0	1,390.82	3,248.00	0	0	911.18	5,550
Wa	0	119.07	113.85	0	597.00	0	114.08	944
S	0	0.36	0.64	0	0	184.00	0	185
U	667.69	887.35	592.22	0	0	0	2,276.74	4,424
Total in 2009	4,194	7,062	4,413	3,248	597	184	3,302	23,000

C cropland, W woodland, G grassland, B for built-up areas, Wa water areas, S stone forests and U unexploited land

Between 1992 and 2004 in the buffer zone, the main part of the increased area of cropland was from woodland (1,200.77 ha), unexploited land (327.39 ha) and grassland (285.55 ha). The main part of the increased area of built-up areas was from grassland (4,269.56 ha), unexploited land (420.55 ha) and water areas (129.07 ha). The main part of the increased area of water areas was from grassland (398.73 ha).

From 2004 to 2009 in the buffer zone, the main part of the decreased area of built-up areas was transformed into grassland (1,390.82 ha) and unexploited land (911.18 ha). The main part of the decreased water bodies' area formed woodland (119.07 ha) and grassland (113.85 ha).

The change rate of ecosystem types

The change rate of ecosystem types in the Shilin Karst and the buffer zone is presented in Table 5.

The results showed that the area of cropland and woodland in the Shilin Karst and the buffer zone increased during 1992–2009. But the increasing rate of cropland in both the Shilin Karst and the buffer zone had slowed down. In the Shilin Karst, the increasing rate of cropland was reduced from 0.86 % (1992–2004) to 0.09 % (2004–2009), while in the buffer zone, it was reduced from 9.34 % (1992–2004) to 8.87 % (2004–2009). Meanwhile, the increasing rate of woodland in the Shilin Karst was from 1.52 % (1992–2004) to 13.62 % (2004–2009). However, in the buffer zone, the decreasing rate of woodland was 1.73 % from 1992 to 2004, while the increasing rate was 6.04 % from 2004 to 2009.

The built-up areas in the Shilin Karst and the buffer zone increased from 1992 to 2004 and decreased from 2004 to 2009. The increasing rate of built-up area was 108.80 % in the Shilin Karst and 54.17 % in the buffer zone from 1992 to 2004, while the decreasing rate of built-up area was 15.44 % in the Shilin Karst and 8.30 % in the buffer zone from 2004 to 2009. In the Shilin Karst, the

Table 5 The annual change rate of ecosystem types in the Shilin Karst and the buffer zone (%)

Ecosystem types	Shilin Karst		Buffer zone	
	1992–2004	2004–2009	1992–2004	2004–2009
Cropland	0.86	0.09	9.34	8.87
Woodland	1.52	13.62	–1.73	6.04
Grassland	–3.72	–5.91	–4.29	4.74
Built-up areas	108.80	–15.44	54.17	–8.30
Water areas	–2.78	19.64	2.65	–7.35
Stone forests	–0.15	–0.04	0.53	–0.11
Unexploited land	–2.16	–7.02	–1.97	–5.07

decreasing rate of water areas was 2.78 % from 1992 to 2004, and the increasing rate was 19.64 % from 2004 to 2009. In the buffer zone, the increasing rate of water areas was 2.65 % from 1992 to 2004, and the decreasing rate was 7.35 % from 2004 to 2009.

Ecosystem service value per hectare

Ecosystem service value per hectare in the Shilin Karst and the buffer zone is presented in Table 6. The value per hectare was 58,136.15 Yuan/ha in woodland, 7,039.88 Yuan/ha in grassland, 44,699.39 Yuan/ha in water areas and 5,785.54 Yuan/ha in stone forests.

Changes in ecosystem service value

Ecosystem service value in the Shilin Karst and the buffer zone is presented in Table 7. In the Shilin Karst, the total ecosystem service value was 258.78 million Yuan in 1992, 280.16 million Yuan in 2004 and 449.82 million Yuan in 2009 at the average annual increasing rate of 4.34 % from 1992 to 2009. The average annual increasing rate of the total ecosystem services value from 1992 to 2004 and from 2004 to 2009 was 0.69 and 12.11 % respectively. Ecosystem service value per hectare was 21.6 thousand Yuan

Table 6 Ecosystem service value per hectare in the Shilin Karst and the buffer zone (Yuan/ha)

Items	Ecosystem service value per hectare			
	Woodland	Grassland	Water areas	Stone forests
Provisioning				
Food production	–	291.71	97.24	0
Raw material	–	48.62	9.72	0
Regulating				
Climate regulation	2,389.10	875.12	447.29	0
Gas regulation	28,211.41	777.89	–	0
Water regulation	11,946.05	777.89	19,816.70	29.17
Air purification	1,778.82	–	–	–
Waste disposal	–	1,273.79	17,677.50	9.72
Supporting				
Nutrient cycling	219.23	–	–	–
Soil formation and retention	9,574.34	1,896.10	9.72	19.45
Biodiversity protection	2,884.60	1,059.87	2,421.18	330.60
Cultural				
Recreation and culture	1,132.60	38.89	4,220.04	5,396.60
Total	58,136.15	7,039.88	44,699.39	5,785.54

–, Function of the ecosystem service does not play a key role in the study

Table 7 Ecosystem service value in the Shilin Karst and the buffer zone (10⁴ Yuan/year)

	Shilin Karst			Buffer zone		
	1992	2004	2009	1992	2004	2009
Woodland						
Provisioning	–	–	–	–	–	–
Regulating	16,400.39	19,396.79	32,610.18	30,362.89	24,042.09	31,302.58
Supporting	4,690.92	5,547.97	9,327.33	8,684.55	6,876.64	8,953.32
Cultural	419.06	495.63	833.25	775.83	614.32	799.84
Total	21,510.37	25,440.39	42,770.76	39,823.27	31,533.05	41,055.74
Grassland						
Provisioning	180.14	99.82	70.31	250.38	121.43	150.19
Regulating	1,960.89	1,086.59	765.39	2,725.54	1,321.83	1,634.88
Supporting	1,564.59	866.99	610.70	2,174.71	1,054.69	1,304.47
Cultural	20.58	11.41	8.03	28.61	13.88	17.16
Total	3,726.20	2,064.81	1,454.43	5,179.24	2,511.83	3,106.70
Water areas						
Provisioning	0.90	0.60	1.19	7.66	10.10	6.39
Regulating	318.71	212.47	421.15	2,716.61	3,581.68	2,265.11
Supporting	20.42	13.61	26.98	174.05	229.48	145.12
Cultural	35.45	23.63	46.84	302.15	398.37	251.94
Total	375.48	250.31	496.16	3,200.47	4,219.63	2,668.56
Stone forests						
Provisioning	0	0	0	0	0	0
Regulating	1.79	1.75	1.75	0.68	0.72	0.72
Supporting	16.07	15.79	15.75	6.09	6.48	6.44
Cultural	247.70	243.39	242.85	93.90	99.84	99.30
Total	265.56	260.93	260.35	100.67	107.04	106.46
Total	25,877.61	28,016.44	44,981.70	48,303.65	38,371.55	46,937.46
10 ⁴ Yuan/ha	2.16	2.33	3.75	2.10	1.67	2.04

–, Function of the ecosystem service does not play a key role in the study

in 1992, 23.3 thousand Yuan in 2004 and 37.5 thousand Yuan in 2009. The woodland ecosystem service value increased from 215.10 million Yuan in 1992 to 427.71 million Yuan in 2009 at an average annual increasing rate of 5.81 % from 1992 to 2009, while the average annual increasing rate from 1992 to 2004 and from 2004 to 2009 was 1.52 and 13.62 % respectively. The grassland ecosystem service value showed a decreasing trend from 37.26 million Yuan in 1992 to 14.54 million Yuan in 2009 at an average annual decreasing rate of 3.59 % from 1992 to 2009. The water areas ecosystem service value decreased from 3.75 million Yuan in 1992 to 2.50 million Yuan in 2004 and increased to 4.96 million Yuan in 2009. The stone forests ecosystem service value showed a decreasing trend from 2.66 million Yuan in 1992 to 2.60 million Yuan in 2009.

In the buffer zone, the total ecosystem service value was 483.04 million Yuan in 1992, 383.72 million Yuan in 2004

and 469.37 million Yuan in 2009. The average annual decreasing rate of the total ecosystem service value from 1992 to 2004 was 1.71 %, while the average annual increasing rate from 2004 to 2009 was 4.46 %. Ecosystem service value per hectare was 21.0 thousand Yuan in 1992, 16.7 thousand Yuan in 2004 and 20.4 thousand Yuan in 2009. The woodland ecosystem service value decreased from 398.23 million Yuan in 1992 to 315.33 million Yuan in 2004 and increased to 410.56 million Yuan in 2009. The grassland ecosystem service value decreased from 51.79 million Yuan in 1992 to 25.12 million Yuan in 2004 and increased to 31.07 million Yuan in 2009. The water areas ecosystem service value increased from 32.00 million Yuan in 1992 to 42.20 million Yuan in 2004, and decreased to 26.69 million Yuan in 2009. The stone forests ecosystem service value increased from 1.01 million Yuan in 1992 to 1.07 million Yuan in 2004 and decreased to 1.06 million Yuan in 2009.

Spatial distribution of ecosystem service value in 2009

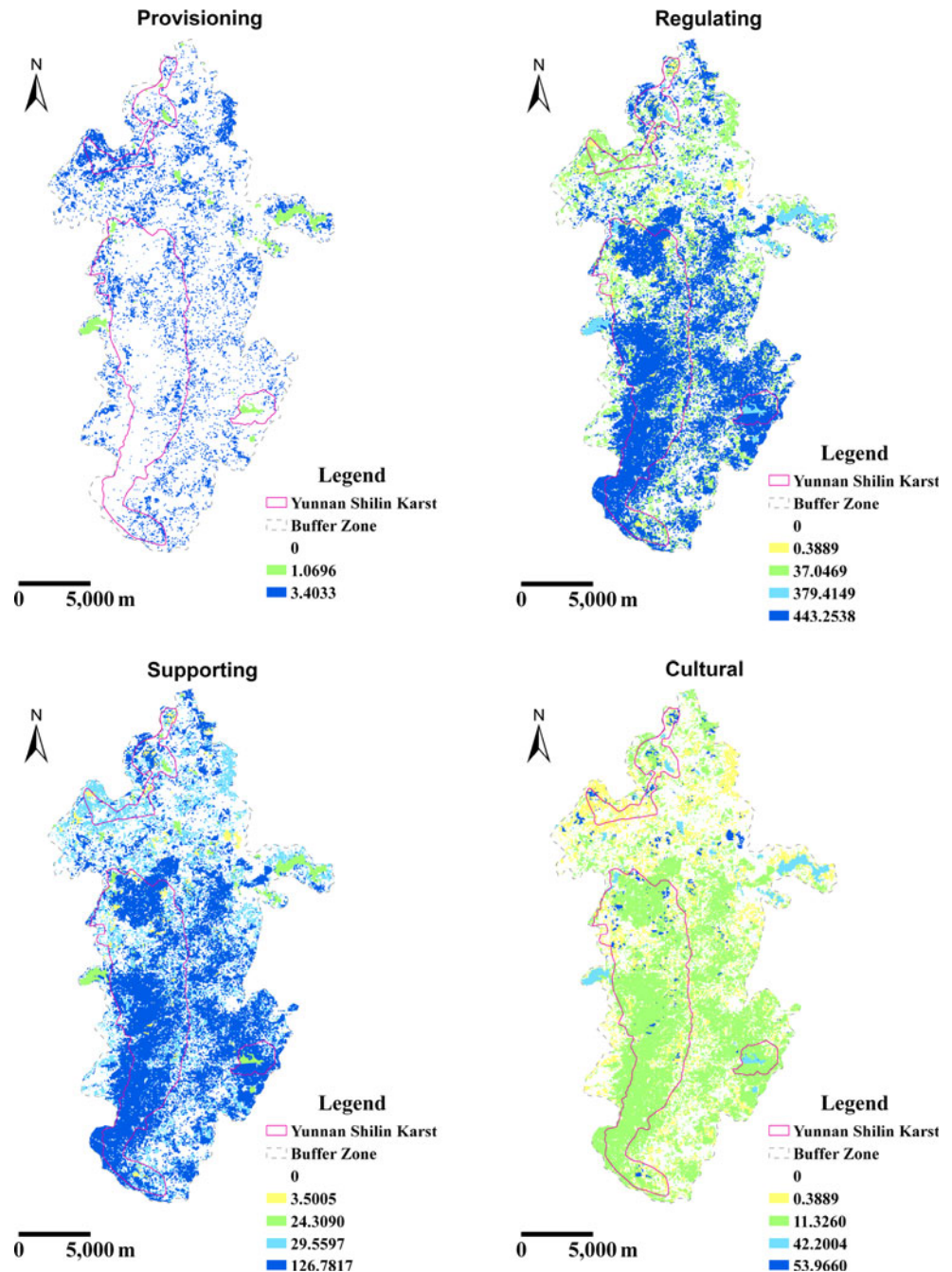
There are differences in the spatial distribution of provisioning, regulating and supporting, and cultural ecosystem service value in the Shilin Karst and the buffer zone (Fig. 4) and in the total ecosystem service value in 2009 (Fig. 5).

Provisioning ecosystem service value in 2009 varied from 0 to 3.40 Yuan for each 10-m cell. Provisioning ecosystem service value in most of the Shilin Karst was 0 to 1.07 Yuan per 100 m², while in most of the buffer zone it was 1.07 to 3.40 Yuan per 100 m². As a result, the Shilin

Karst had less provisioning ecosystem service value per 100 m² than the buffer zone.

Regulating ecosystem service value in 2009 varied from 0 to 443.25 Yuan for each 10-m cell. Regulating ecosystem service value in most of the northern part of the Shilin Karst and the buffer zone was 0 to 37.05 Yuan per 100 m², while in most of the other part 379.41 to 443.25 Yuan per 100 m². As a result, the northern part of the Shilin Karst and the buffer zone had less regulating ecosystem service value per 100 m² than the other parts of the Shilin Karst and the buffer zone.

Fig. 4 Spatial distribution of ecosystem service value in 2009: provisioning, regulating, supporting and cultural (Yuan/10-m cell)



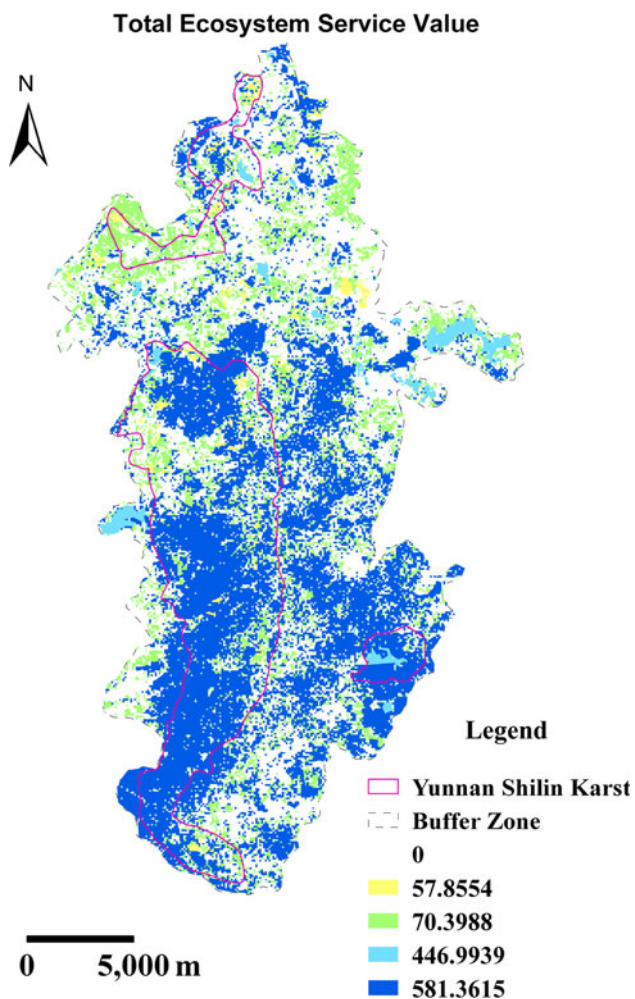


Fig. 5 Spatial distribution of total ecosystem service value in 2009 (Yuan/10-m cell)

Supporting ecosystem service value in 2009 varied from 0 to 126.78 Yuan for each 10-m cell. Supporting ecosystem service value in most of the northern part of the Shilin Karst and the buffer zone was 0 to 29.56 Yuan per 100 m², while in most of other parts 29.56 to 126.78 Yuan per 100 m². As a result, the northern part of the Shilin Karst and the buffer zone had less supporting ecosystem service value per 100 m² than the other parts of the Shilin Karst and the buffer zone.

Cultural ecosystem service value in 2009 varied from 0 to 53.97 Yuan for each 10-m cell. Cultural ecosystem service value in most of the northern part of the Shilin Karst and the buffer zone was 0 to 0.39 Yuan per 100 m², while in most of the remaining area it was 0.39 to 53.97 Yuan per 100 m². As a result, the northern part of the Shilin Karst and the buffer zone had less cultural ecosystem service value per 100 m² than the other parts.

The total ecosystem service value in 2009 varied from 0 to 581.36 Yuan for each 10-m cell. Total ecosystem

service value in most of the northern part of the Shilin Karst and the buffer zone was 0 to 70.40 Yuan per 100 m², while in most of the other parts it was 446.99 to 581.36 Yuan per 100 m². As a result, the northern part of the Shilin Karst and the buffer zone had less ecosystem service value per 100 m² than the other parts.

Discussion and conclusions

A great change in the ecosystem service value has taken place in the Shilin Karst and the buffer zone since the nomination to the World Heritage List. The total ecosystem service value was 258.78 million Yuan in 1992, 280.16 million Yuan in 2004 and 449.82 million Yuan in 2009 at an average annual increase of 4.34 % from 1992 to 2009. In the buffer zone, the total ecosystem service value was 483.04 million Yuan in 1992, 383.72 million Yuan in 2004 and 469.37 million Yuan in 2009. The average annual decrease in total ecosystem service value from 1992 to 2004 was 1.71 %, while the average annual increase from 2004 to 2009 was 4.46 %. The trend was an increase in the total ecosystem service value from the increase in the natural and semi-natural ecosystem areas. In the Shilin Karst, an increase occurred in woodland and a decrease in unexploited land, while in the buffer zone, woodland increased and unexploited land decreased since 2004. The main reason for this was slowing down in the increasing rate of cropland, and decrease in built-up areas since 2004 in both the Shilin Karst and the buffer zone. The driving force comes from governmental policy. The following key measures have been taken since 1992: (1) organizing the integral investigation of Shilin Karst from 1993 to 1996, including the investigation of karst geology, hydrogeology, vegetation, agricultural production and farmers' living conditions; (2) taking effective actions for strict conservation of natural vegetation since 1996, e.g., stopping farming for re-vegetation in the core zones of the Shilin Scenic and Historical Area, carrying out eco-compensation for 1,500 Yuan per hectare to stop farming in steep slope cropland, promoting re-vegetation since 2001, and increasing the eco-compensation standard to 7,500 Yuan per hectare since 2006; (3) revising the Master Plan of the Shilin Scenic and Historical Area in 2002; (4) seeking financial support from the central government, provincial government and non-governmental organizations for natural restorations; and (5) developing local tourist industry.

Ecosystem service value indicates how much benefits the ecosystem provides to our human beings. The methods make the local government and stakeholders pay more close attention to environmental degradation, resources reduction and biodiversity loss. However, there are differences in values yielded by different ecosystems over the

whole target region (Chen et al. 2009). That is why different researchers use different methods and research subjects to evaluate ecosystem service value. The government of the Shilin Yi Nationality Autonomous County increased the ecosystem service value of the Shilin Karst by protecting world-significant geological landscapes. The Shilin Karst's joining in the UNESCO's National Geopark Network in 2004 has also perfected the condition for the nomination of the Shilin Karst to the World Heritage List.

To achieve the conservation and management goals such as biodiversity, ecosystem integrity and sustainable development, ecosystem-based conservation and management is of great significance. It seeks to transcend arbitrary political and administrative boundaries, to achieve more effective, integrated management of resources and ecosystems at regional and landscape scales (Slocombe 1998). While changes in land use/land cover may significantly affect the ecosystem processes and functions, the ecosystem services may not necessarily decrease greatly if there is a concomitant increase in the size of other land cover types that provide a greater level of ecosystem services (Kreuter et al. 2001). This may well explain that the increase of total ecosystem service value was mainly caused by the increase of woodland, while grassland or water areas had not necessarily increased.

The spatial distribution analysis in 2009 showed that the northern part of the Shilin Karst and the buffer zone had less ecosystem service value per 100 m² than the other parts of the Shilin Karst and the buffer zone. Therefore, conservation should be further carried out in the northern part.

Collecting and obtaining data and mapping the spatial distribution of ecosystem service value are made more easy with remote-sensing images and geographic information systems (GIS), which can be better applied to guide future protection and management work. In addition, GIS can also be used to carry on a variety of other spatial analyses (Troy and Wilson 2006; Grêt-Regamey et al. 2008; Chen et al. 2009; Raymond et al. 2009). It is a useful tool for the deep analysis of the study. From the protection and management point of view, the study of spatial distribution of ecosystem service value makes the approaches of valuation more useful to guide future protection and management work.

By virtue of such ecosystem service value assessment, the government of the Shilin Yi Nationality Autonomous County has taken further measures to improve conservation and management since 2008, for example, the standard for eco-compensation has increased to RMB 30 million Yuan per year from Shilin's tourist industry income in order to adjust the industry structure, improve the rural conditions and let more local farmers be employed in Shilin's tourist industry. Moreover, the government provides 250 Yuan per month to each senior citizen for their living cost and

250 Yuan per month to each young student for ecological restoration within the Shilin Karst World Heritage Sites and buffer zones.

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