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Synergy and regulation of the South China Karst WH site integrity protection and the buffer zone agroforestry development

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Abstract

The Natural World Heritage site (NWH) has a dual role of protection and utilization. The buffer zone of the South China Karst (SCK) World Heritage (WH) site is scattered with village dwellings, which adds pressure to preserve the outstanding universal value (OUV) and integrity protection of the WH site. The development of agroforestry is an essential means to maintain rural livelihoods, protect the ecological environment, and realize the protection and development of the heritage site. Studying the synergy and regulation of the heritage site integrity protection and the buffer zone agroforestry development is essential. This study takes the Shibing and Libo–Huanjiang karst WH as the study areas and administrative villages as the evaluation unit. From 2020 to 2023, through data methods such as remote sensing data interpretation, information data survey and collection, comprehensive index analysis, coupling coordination degree model, and GIS spatial analysis, a systematic study was conducted on the basic frontier research, synergy relationship, and regulation of the heritage site integrity protection and the buffer zone agroforestry development. The results demonstrate that the Shibing and Libo–Huanjiang karst WH sites integrity protection and agroforestry development in the buffer zone have a high coupling degree and a good coupling coordination relationship. This reveals that the heritage site integrity protection and the buffer zone agroforestry development are an interconnected and mutually influential whole, which the synergistic relationship between them is developing in a positive direction; The buffer zone agroforestry development lags behind the heritage site integrity protection, based on which proposed the regulatory measures for the synergy development of the heritage site integrity protection and agroforestry development in the buffer zone. The findings in this study provide references for the synergies development of the WH karst site integrity protection and agroforestry development in the buffer zone.

Keywords Integrity protection, The buffer zone agroforestry, Coupling coordination degree, Regulation measures, The South China Karst

Introduction

Karst landscapes account for approximately 15% of the total land area of the world and 1/3 of the total land area of China [1, 2]. The South China Karst (SCK) World Heritage (WH) sites are an essential part of the Natural World Heritage (NWH). The WH site is a treasure that needs to be protected and appreciated by human beings, and WH protection is an urgent task. Authenticity and/or integrity and protection and management are essential bases for the WH nomination the three pillars of outstanding universal value (OUV) of the WH site and

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essential tools for the WH protection management and assessment. Among them, integrity measures the wholeness and intactness of the natural and/or cultural heritage and its attributes. The integrity principle is an essential guiding principle of the NWH protection and fundamental to ensure the sustainability of the heritage site, which not only provides the WH site's value, but also delineates the principle scope of heritage protection [3–5]. The SCK is a NWH project proposed by the Chinese government to the UNESCO World Heritage Committee in batches [6]. The peripheral areas of the buffer zone of the WHS of SCK area are scattered with village dwellings, and there has been a conflict between the demand for land, forests and other natural resources for human survival and development and the conservation of resources. Especially with the socio-economic development, local people's pursuit of modern life has increased the intensity of human activities, adding pressure to the protection of the integrity and the whole natural resources and environment in heritage sites.. The SCK, the world's largest contiguous karst region, has undergone severe ecological degradation associated with the interaction of fragile natural attributes and human activities [7]. Compared with other NWHs, the uniqe environment and human activities in the karst region have had a multifaceted impact on the protection and development of the integrity of the WH karst.

Currently, some scholars have conducted studies related to heritage site integrity protection [4, 5, 8–12], the development of agroforestry in the buffer zone [13–17], and the synergy between heritage protection and tourism [18–21], but there are fewer studies on the synergy of the two. Demonstrating of WH value and community development is an important way for sustainable protection and management of WH properties [22]. Any construction projects at the WH site and the buffer zone that could potentially affect heritage value need to be communicated to the WH center in protection management status reports ensuring that the OUV and integrity of the heritage site are adepuate protection [23]. As global perceptions of heritage protection evolve, it is realized that heritage protection must be based first and foremost on the sustainable development of local people's livelihoods [24]. Therefore, to ensure the heritage site integrity protection and the buffer zone sustainability development, the harm of the buffer zone development to the heritage site should be solved through the industrial development guidance adjustment, and the industrial structure of the buffer zone should not conflict with the protection requirements of the heritage site. Research shows that agroforestry development in the buffer zone is conducive to socio-economic development, and protects the natural ecological environment and nature reserves from human interference, especially for the WH karst areas where the ecological environment is fragile and the regional economy is relatively backward [17, 25]. What is more, Chen [26] reviewed the NWH site integrity protection and buffer zone agroforestry development, proposed a synergistic perspective of the agroforestry sustainable development to study the coupling coordination of the two. Therefore, study the synergy of the WH karst site integrity protection and the buffer zone agroforestry development is crucial.

The Shibing (from now on referred to as "Shibing karst") and Libo–Huanjiang WH karst site (from now on referred to as "Libo–Huanjiang karst") are an important part of the SCK series of the NWH site [27], which has the properties of a national nature reserve and scenic spot protection. Its aesthetic and geomorphic values are well protected. A good development model for the buffer zone can ease the pressure on resource use, drive local economic development, and promote NWH protection and management effectiveness [28]. Agroforestry is a traditional production model, originating from family farms, with productive, sustainable, and adaptable land use practices, and sustainability is the most significant advantage of agroforestry [29–31]. Developing the area where the heritage is located needs to balance ecological, social and economic benefits, especially in karst ecologically fragile areas. Using agroforestry production models, economic development goals and the environmental free from damage in the communities surrounding the nature reserve can be maximized [32]. According to the protection concept of core area protection as the main area and buffer zone management and development, the Libo–Huanjiang karst has established a model of buffer zone protection and sustainable development, as ecological restoration of warp and fruit forests [33]. Therefore, it is of great practical significance and promotion for the protection and sustainable development of the heritage site to study the coupling of the heritage site integrity protection and the buffer zone agroforestry development in the Shibing and Libo–Huanjiang karst.

This study aims to explore the synergy relationship between heritage site integrity protection and the buffer zone agroforestry development to promote balanced development of heritage site protection and buffer zone. We used the comprehensive evaluation,coupling degree,and coupling coordination models to achieve this objective. We conducted empirical analyses on the interactive relationship between heritage site integrity protection and the buffer zone agroforestry development in nine Shibing and Libo–Huanjiang karst villages from 2015 to 2020. The research results aim to provide scientific reference for the protection and development of the WH site.

Study area

The SCK (97°–117° E, 20°–35° N) is centered on the Guizhou plateau (Fig. 1), including Yunnan, Guizhou, Guangxi, Sichuan, Hunan, Hubei, Guangdong, and Chongqing, has an approximate area of 1.938×106 km^2 [7]. The unique landform types, ecosystems, biodiversity, natural beauty, and developmental evolution are of remarkable global value and significance. The SCK protects and demonstrates the best examples of karst features and geomorphic landscapes and thus has OUV. The Shibing karst and Libo–Huanjiang karst were inscribed on the World Heritage List (WHL) in 2007 and 2014 for meeting the WH evaluation criteria (vii) aesthetic and (viii) geomorphological, respectively. The SCK is an incomparable property given by nature to humankind, a fantastic realm where humanity and nature live in harmony. Regarding the lithological basis of karst development, karst landform types, and karst development and evolution, it comprehensively complements and completes the integrity and authenticity of SCK with the premise of OUV.

Shibing karst is located in the northern part of Shibing County, Qiandongnan Miao and Dong Autonomous Prefecture, Guizhou Province, with an average elevation of 912 m. It is located in the humid climate zone of the Central Subtropical Monsoon, with the characteristics of the humid climate of the Central Subtropical Mountains with warm spring and cool summer, four distinct seasons and

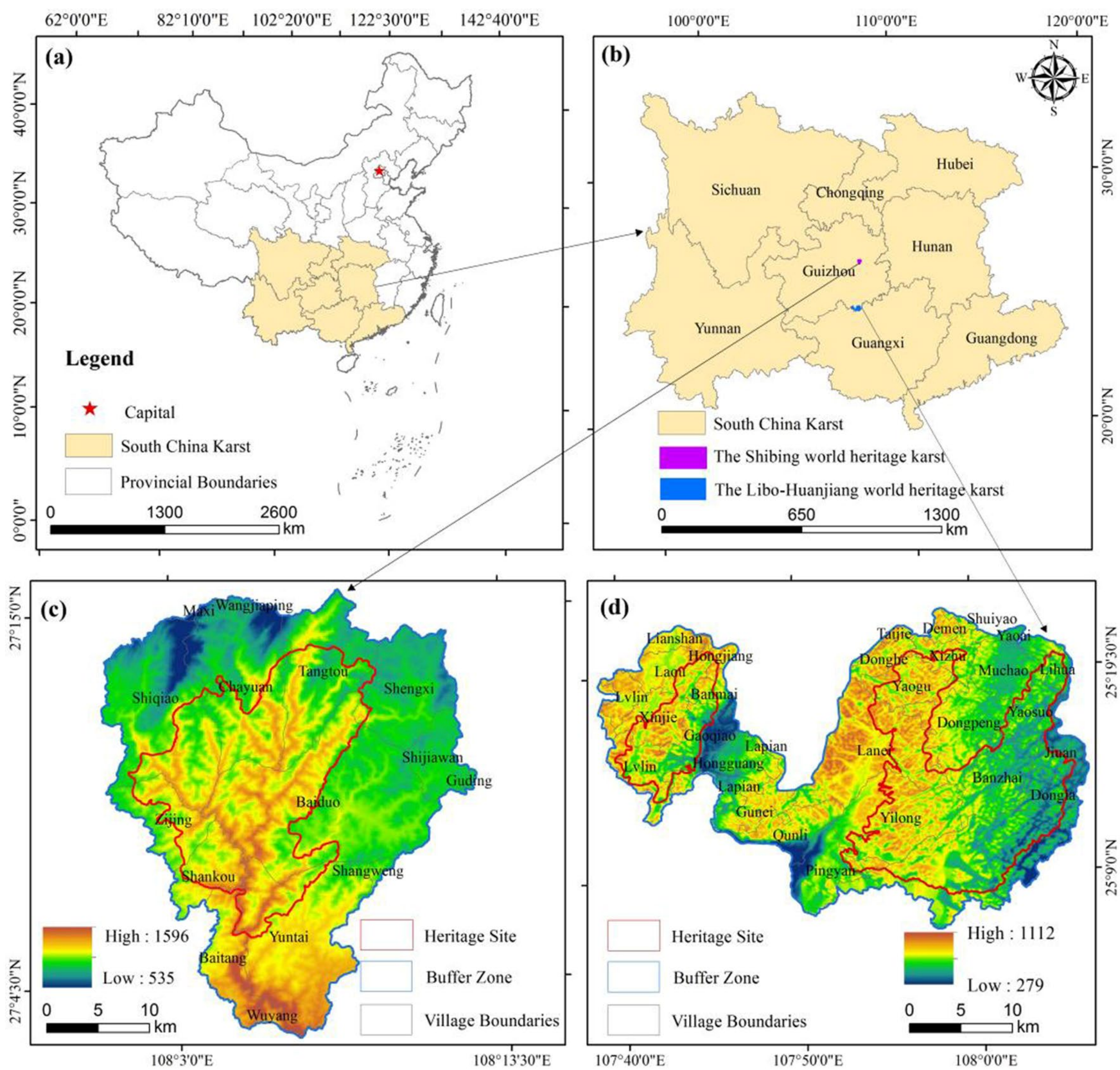

Fig. 1 Location map of the study area. **a** Location of the SCK in China; **b** location of the study area in SCK; **c** study area village boundaries of Shibing karst; **d** study area village boundaries of Libo–Huanjiang karst)

abundant precipitation. The total area of Shibing karst is 28,295 hm^2, of which 10,280 hm^2 is the heritage site and 18,015 hm^2 is the buffer zone, with the central latitude coordinates of 108° 05′ 40″ E and 27° 10′ 16″ N. To protect the OUV and integrity of the heritage site and to promote the buffer zone socio-economic development, the villages in the buffer zone of the Shibing WH karst site are actively implementing the "Party Branch Leading-Cooperative Promoting-Farmers' Participation" model of joint action, developing agroforestry models such as "fruit forest-medicinal materials" and "fruit forest-honey" with local characteristics (Fig. 2).

The Libo–Huanjiang karst is located at the junction of Libo County, Qiannan Prefecture, Guizhou Province, Huanjiang County, Hechi City, Guangxi Zhuang Autonomous Region. The scope of the heritage site mainly includes the Maolan National Nature Reserve in Guizhou, the Daqikong and Xiaoqikong scenic areas of the Zhangjiang National Scenic Area, and the Guangxi Mu Lun National Nature Reserve (Fig. 1). The total area of Libo–Huanjiang karst is 84,575hm^2, of which 36,647hm^2 is the heritage site, and 47928hm^2 is the buffer zone, with the central latitude coordinates of 107° 58′ 30′′–107° 59′ 40′′ E–25° 09′ 27′′–25° 13′ 15′′ N. According to the principle of "conservation-oriented, scientific development and sustainable use" the conservation concept of the core area protection and buffer zone management and development. It has effectively improved the environmental quality of the heritage site while promoting the rapid development of the community economy, forming a model of buffer zone protection and sustainable development, and realizing the coordinated development of the WH site [33]. In addition, Libo–Huanjiang karst makes full use of the "three gardens" such as plum garden, fruit garden and forest garden, forming three-dimensional ecological industry development model of "under-forest raising, knotting greengage on the forest, tying epidendrum in the forest and growing herbs under the forest" is formed (Fig. 3).

Data sources

The data used in this paper mainly include remote sensing data, socio-economic data, and vector data. The remote sensing data were obtained from the geospatial data cloud (http://www.gscloud.cn/) by downloading landsat8 satellite images with 30 m spatial resolution in 2015 and 2020, respectively; the DEM data were obtained from the raster data with 30 m spatial resolution from the geospatial data cloud (http://www.gscloud.cn/); the administrative village social data and economic data were collected by the team from the village committees of each village domain within the coordinating jurisdiction of each township government, respectively.

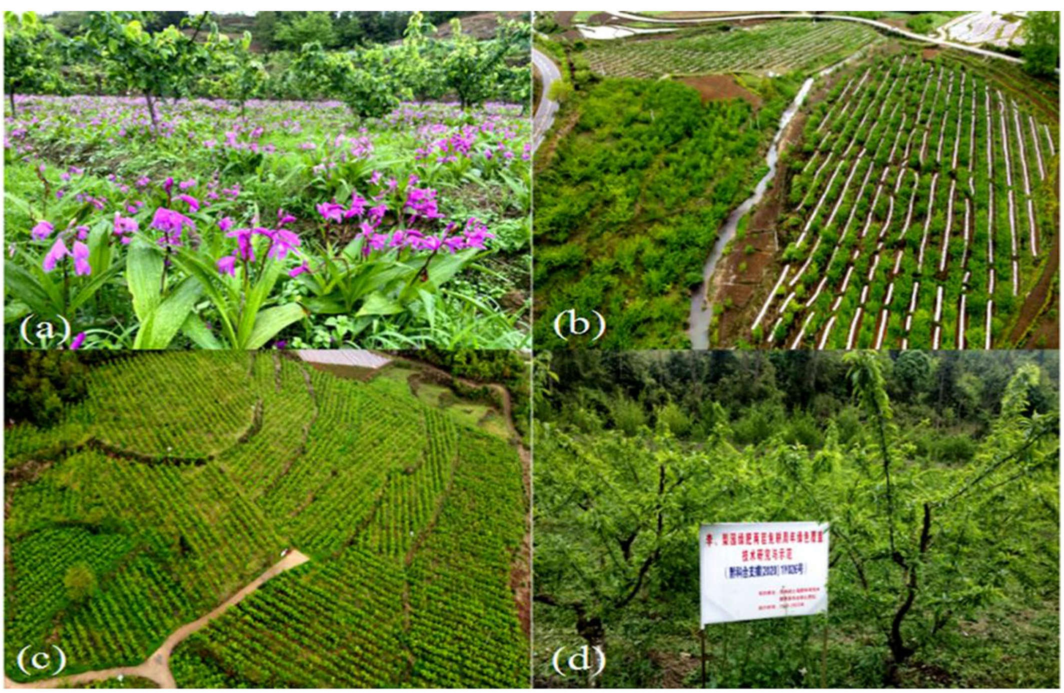

Fig. 2 The buffer zone agroforestry development of Shibing karst (**a** Pears-Bletilla striata; **b** Pears-Passion fruit; **c** Pears-Roast tobacco-Salvia miltiorrhiza; **d** Pears-green manure)

Fig. 3 The buffer zone agroforestry development of Libo–Huanjiang karst (**a** Blood orange-Underforest raising; **b** Blood orange-Pomelo-Banana; **c** Tongcao-Greengage-Underforest raising; **d** Greengage-Epidendrum-Dysosma versipellis)

Methods

Index system construction

The heritage site integrity protection and the buffer zone development have incredibly complex interactions. Agroforestry has become an essential strategy in reconciling the contradictory requirements of environmental protection and economic development in ecologically fragile areas, which can achieve a mutually beneficial relationship between ecological and socio-economic needs and promote sustainable development of the region [34, 35], but may also threaten heritage site protection. The fragile environment of the WH karst site will not only affect the security of the heritage site to varying degrees, but it will also limit agroforestry development in the buffer zone after destroying the environmental system. From an objective point of view, there are various contradictions and interactions between heritage site protection and buffer zone development. Therefore, the system consisting of the heritage site integrity subsystem and the buffer zone agroforestry subsystem can be defined as a coupled system. The study of coupled coordination degree relationship is the basis for achieving sustainable development of heritage site protection and buffer zone (Fig. 4).

Reference to the operation guide on the definition of heritage integrity, from the landscape integrity and heritage value embodied integrity [3, 10, 36] selection index evaluation heritage integrity protection (Table 1).

Among them, these indicators are based on remote sensing data to interpret land use and determine their index value. The kappa coefficient exceeds 0.85, indicating that the interpretation data has passed the consistency test, and the team conducted field verification on the field in 2015 and 2020. However, the uniqueness and richness of landscape beauty, reflects the integrity of the heritage aesthetic and geomorphological value. Through the heritage site in 2015 and 2020 in the research area of the same point photos made into slides, and five experts on karst WH protection and 15 scholars engaged in heritage research were invited, using the SBE method for landscape aesthetic and geomorphological evaluation index.

The understanding of integrity, is a matter of compatibility between sustainable development and conservation [10]. If regional activities are ecologically sustainable, they can also be consistent with the OUV highlighted by natural areas [3]. Moreover, many studies have shown that ecological sustainability is the most significant advantage of agroforestry [37, 38]. Consequently, the sustainability of agroforestry in the buffer zone was evaluated comprehensively in terms of

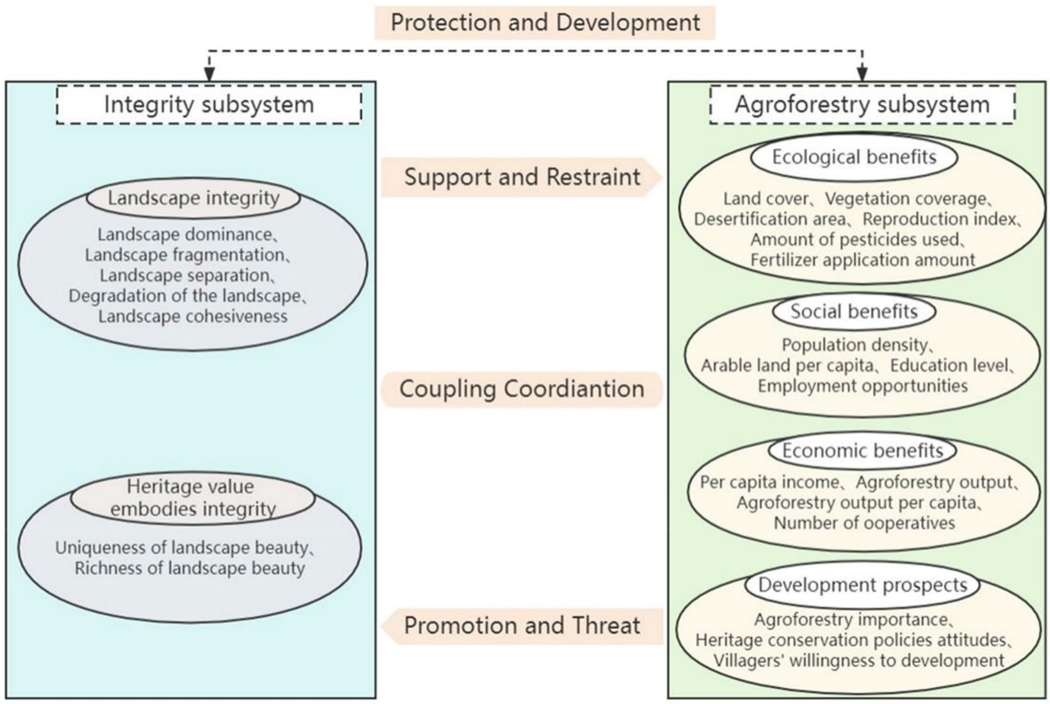

Fig. 4 Relationship of coupling coordination of the heritage site integrity protection and agroforestry development in the buffer zone

Table 1 Evaluation indicators and weights of the integrity protection of heritage site

Dimension	Specific indicators	Explanation of the indicators	Computing method	Index type	Weight and order
Landscape integrity	X1:Landscape dominance	The ecological service value, aesthetic value, ecological price of different landscape types	Remote sensing interpretation	+	0.2863/1
	X2:Landscape fragmentation	The complexity of the spatial structure of the landscape reflects the degree of human interference with the landscape	Remote sensing interpretation	–	0.0867/7
	X3:Landscape separation	The separation of individual distribution of different patches in a landscape type	Remote sensing interpretation	–	0.0977/6
	X4:Degradation of the landscape	The ratio of area of each landscape type and time difference of two remote sensing data	Remote sensing interpretation	–	0.1035/5
	X5:Landscape cohesiveness	Measure the complexity of the landscape spatial pattern	Remote sensing interpretation	+	0.1048/4
Heritage value embodied integrity	X6:Uniqueness of landscape beauty	Reflect the integrity of the aesthetic and geomorphological value of the heritage site	Five-point scale method	+	0.1663/2
	X7:Richness of landscape beauty	Reflect the integrity of the aesthetic and geomorphological value of the heritage site	Five-point scale method	+	0.1554/3

Table 2 Evaluation indicators and weights of sustainable development of agroforestry in the buffer zone

Dimension	Specific indicators	Explanation of the indicators	Computing method	Index type	Weight and order
Ecological benefits	Y1:Land cover	Land use type and area of the heritage site and the buffer zone	Remote sensing interpretation	+	0.0364/11
	Y2:Fraction of vegetation coverage	Percent vegetation coverage in the heritage site and the buffer zone	NDVI inversion	+	0.2001/1
	Y3:Desertification area	Different rocky desertification levels of the heritage site and the buffer zone	Remote sensing interpretation	−	0.0300/14
	Y4:Reproduction index	Reflect the utilization degree of land resources of the planting mode	Statistical data	+	0.0213/16
	Y5:Amount of pesticides used	The influence of the use per unit sown area on the environment and biodiversity of the heritage site and buffer zone	Statistical data	−	0.0204/17
	Y6:Fertilizer application amount	The impact of the fertilizer used per mu on the soil and water in the heritage land and buffer zone	Statistical data	−	0.1002/2
Social benefits	Y7:Population density	Number of population living on each unit of land area	Statistical data	+	0.0358/12
	Y8:Arable land per capita	The amount of all cultivated land within a particular area divided by the total population within the area	Statistical data	+	0.0231/15
	Y9: Education level	The proportion of junior high school and above	Statistical data	+	0.0501/9
	Y10:Employment opportunities	Amount of labor force contained in the unit area of the system	Statistical data	+	0.0702/5
Economic benefits	Y11:Per capita income	The product value created by the labor force every year and the impact of residents' income on heritage protection	Statistical data	+	0.0823/3
	Y12:Agroforestry output	Agroforestry output	Statistical data	+	0.0532/8
	Y13:Agroforestry output per capita	The total output value of regional agroforestry is divided by the value obtained by the total population of the region	Statistical data	+	0.0551/7
	Y14:Number of cooperatives	Total number of cooperatives	Statistical data	+	0.0806/4
Development prospects	Y15:Agroforestry important	Residents attach great importance to the development of agroforestry	Five-point scale method	+	0.0664/6
	Y16:Heritage conservation policies support attitudes	Residents' support and attitude towards the protection and management policies of heritage sites	Five-point scale method	+	0.0343/13
	Y17:Villagers' willingness to plant	Residents' willingness to develop agroforestry	Five-point scale method	+	0.0404/10

ecological-social-economic-development prospects by referring to relevant research results on the sustainable development of agroforestry and combining the administrative village study scale (Table 2).

The data on agroforestry is mainly obtained from the team's communication and interviews with the village committees and typical farmers in the buffer zone from 2015 to 2020 in order to get the detailed data agroforestry and industry-led socio-economic data. The survey was conducted through questionnaires or face-to-face interviews with government staff, cooperative staff, and agroforestry practitioners. In addition, data inquiry and screening were conducted through local county and township statistical yearbooks, etc., to obtain effective data finally.

Calculation of index weights

Since several index attributes are involved, the mutual weights of these indexes need to be determined before evaluating the targets based on remote sensing images and statistical data. The objectivity and reasonableness of the index weights greatly influence the final evaluation results. This paper selects the entropy value assignment method to calculate the consequences. The main steps are as follows:

1. Form the original indicator data. Let X_{ij} be the initial actual value of the jth indicator in year (i=1,2…,m; j=1,2…,n).
2. The data were dimensionless processed. Let Y_{ij} be the standardized value of the index. To eliminate the effect of unit differences, therefore, the outlier standardization method is chosen for the positive and negative indicator data, which is dimensionless, i.e., m(1,2,…i) samples, n(1,2… j) indicators are linearly transformed to map them to [0,1].

The raw data X_{ij} are positive indicators, normalized by the formula:

$$Y_{ij} = \left[X_{ij} - Min_{(Xi)}\right] / \left[Max_{(Xi)} - Min_{(Xi)}\right] \tag{1}$$

The raw data X_{ij} are negative indicators, normalized by the formula:

$$Y_{ij} = \left[Max_{(Xi)} - X_{ij}\right] / \left[Max_{(Xi)} - Min_{(Xi)}\right] \tag{2}$$

where X_{ij} is the original data, Y_{ij} is the standardized value, $Max_{(xi)}$ refers to the maximum value of the first indicator, $Min_{(xi)}$ is the minimum value of the first indicator.

3. Entropy value weighting method. The basic principle of the entropy value method is that the greater the degree of difference between the indicator values of a specific indicator, the smaller the information entropy, the greater the amount of information provided by the indicator, and the greater the weight of the indicator. Conversely, the smaller the degree of difference between the values of a specific indicator, the greater the information entropy, the smaller the amount of information provided by the indicator, and the smaller the indicators' weight [39]. The specific calculation process is as follows:

First, calculate the weight of the jth indicator in the year i:

$$Y_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \tag{3}$$

Next, the entropy value of the jth indicator is calculated.

$$e_i = -k \sum_{i=1}^{m} Y_{ij} \ln y_{ij} \tag{4}$$

Finally, the weights of each indicator are calculated.

$$W_j = \frac{1 - e_j}{\sum_{i=1}^{n} 1 - e_j} \tag{5}$$

where Y_{ij} is the weight of the jth indicator in year i, X_{ij} is the value of the jth indicator in year i, n denotes the number of villages, e_i is the entropy value, ln is the natural logarithm, k=lnm/1, represents the number of indicators, and W_j is the weight of indicators.

Comprehensive index evaluation model

Referring to the studies of related scholars [36, 40], the linear weighting method is used to measure the integrated development evaluation indexes of the heritage site integrity protection and the buffer zone agroforestry systems, and the development level of both systems is evaluated comprehensively. The integrated evaluation equations of the heritage site integrity protection and the buffer zone agroforestry systems are as follows:

$$U1 = \sum_{j=1}^{m} (W_i \times X_i) \tag{6}$$

$$U2 = \sum_{j=1}^{n} \left(W_j \times Y_i\right) \tag{7}$$

U1 and U2 represent the comprehensive evaluation functions of the integrity protection of heritage site system and agroforestry development in the buffer zone system, respectively—the total scores of the indicators in the two systems. Further, m and n denote the numbers of the corresponding indicators in each subsystem, and W_i and W_j are the weights of the corresponding indicators in each subsystem, respectively. Moreover, X_i and Y_i are the standardized values of the ith indicator, respectively. The comprehensive evaluation function is proportional to the development rate of the two major systems—the higher the score, the faster the development rate, and vice versa.

Coupling coordination degree model

The protection and development of heritage have resulted from mutual coupling and interaction, and introduced the coupling coordination degree model [41, 42] to construct the coupling coordination degree model of heritage site integrity protection and buffer zone agroforestry development by combining the village research scale.

$$C=\sqrt{\frac{U1U2}{\left(\frac{U1+U2}{2}\right)^2}}=\frac{2\sqrt{U1U2}}{U1+U2} \tag{8}$$

$$D=\sqrt{C\times T} \tag{9}$$

$$T=\alpha\times U1+\beta\times U2 \tag{10}$$

where C is the coupling degree of the two subsystems of heritage site integrity protection and buffer zone agroforestry; D is the coupling coordination degree of the two systems of heritage site integrity protection and the buffer zone agroforestry; T is the coordination index of heritage site integrity protection and the buffer zone agroforestry α and β are the parameters to be evaluated, generally the sum of α and β is equal to 1, considering that both are equally important, $\alpha=\beta=0.5$ is taken in this study. U1 is the evaluation index of integrity protection of heritage site; U2 is the evaluation index of agroforestry in the buffer zone; where $D\in[0, 1]$, the larger D, the higher the coupling coordination, the minor D, the lower the coupling coordination; C is the coupling degree, $C\in(0, 0.3]$ is micro coupling, $C\in(0.3, 0.5]$ is light coupling, $C\in(0.5, 0.8]$ iss moderate coupling, $C\in(0.8, 1]$ is high coupling (Table 3).

Results

Integrity protection evaluation of heritage site

The so-called integrity in the field of NWH refers to the relative integrity that gives OUV to the heritage rather than the integrity without limitation, and the coordination between the heritage site protection and the buffer zone socio-economic development should be included in the evaluation [10]. In this paper, the integrity protection evaluation of Shibing and Libo–Huanjiang karst is extended to the buffer zone for assessment, and combined with related research results [36], the integrity evaluation value is divided into five levels according to the natural interruption point grading method: Level I (0–0.3), Level II (0.3–0.5), Level III (0.5–0.6), Level IV (0.6–0.7) and Level V (0.7–1). The closer the distribution value is to 0–0.3 (I), the lower the degree of integrity protection; the closer the matter is to 0.7–1 (V), the higher the degree of integrity protection.

There is a clear spatial distribution difference in the integrity protection evaluation of Shibing and Libo–Huanjiang karst (Figs. 5, 6). The area of integrity protection evaluation of Shibing karst level V accounted for the most significant proportion, and in 2015, the area was 241.75 km^2, accounting for 85.44% of the study area. In 2020, the integrity protection evaluation level V increased, compared to 2015, by 15.32 km^2, with an area of 257.07 km^2, accounting for 90.85% of the study area. The integrity protection evaluation class I

Table 3 Classification criteria and characteristics of coupling degree and coupling coordination degree

Coupling degree	C	Coupling coordination degree	D	Features
High coupling	$0.8<C\le 1$	Quality coordination	$0.90<D\le 1.00$	The benign coupling of the two systems becomes stronger and gradually develops in the direction of order and is at a high level of coordinated coupling
		Good coordination	$0.80<D\le 0.90$	
		Moderate coordination	$0.70<D\le 0.80$	
Moderate coupling	$0.5<C\le 0.8$	Elementary coordination	$0.60<D\le 0.70$	The two systems begin to check and match each other, showing benign coupling characteristics
		Reluctant coordination	$0.50<D\le 0.60$	
Light coupling	$0.3<C\le 0.5$	Near-disorder	$0.40<D\le 0.50$	The two systems interact and strengthen each other, constantly influencing and adapting
		Mild disorder	$0.30<D\le 0.40$	
		Moderate disorder	$0.20<D\le 0.30$	
Micro coupling	$0<C\le 0.3$	Serious disorder	$0.10<D\le 0.20$	Shallow level of coupling of the two systems
		Extreme disorder	$0.00<D\le 0.10$	

has the smallest area share, accounting for 0.91% of the study area in 2015 and only 0.38% in 2020. However, the integrity protection evaluation grade II, III, IV area decreased from 2015 to 2020, by 3.89 km^2, 3.59 km^2 and 6.34 km^2, respectively (Table 4).

The integrity protection evaluation of Libo–Huanjiang karst level V has themost significant area share, with an

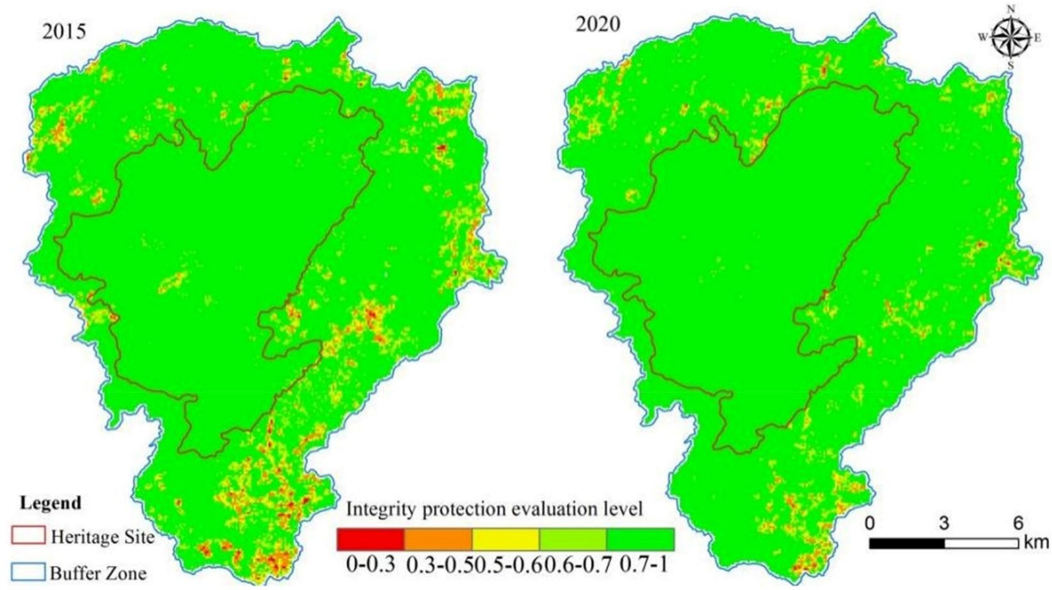

Fig. 5 Evaluation of the integrity protection of the Shibing karst in 2015–2020

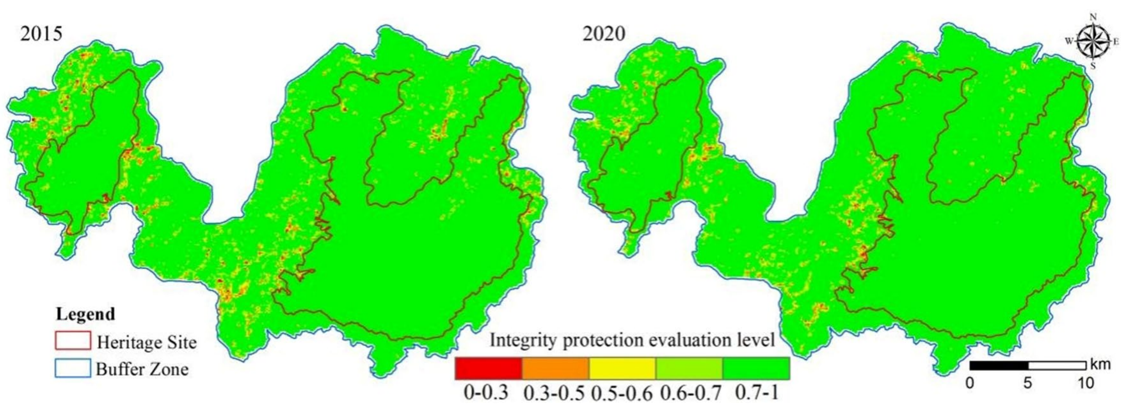

Fig. 6 Evaluation of the integrity protection of the Libo–Huanjiang karst in 2015–2020

Table 4 Integrity protection level and area ratio of Shibing karst in 2015–2020

Integrity grades	2015		2020		2015–2020
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area changes (km^2)
I	2.58	0.91	1.08	0.38	− 1.50
II	10.43	3.69	6.54	2.31	− 3.89
III	12.32	4.35	8.73	3.09	− 3.59
VI	15.87	5.61	9.53	3.37	− 6.34
V	241.75	85.44	257.07	90.85	15.32

area of 742.64 km^2 in 2015, accounting for 87.81% of the study area. In 2020, the integrity protection evaluation level V increased, with a rise of 41.04 km^2, compared to 2015, with an area of 783.68 km^2, accounting for 92.66% of the study area. The integrity protection evaluation level I has the smallest area share, accounting for 0.37% of the study area in 2015 and only 0.19% in 2020. In 2015–2020, the integrity protection evaluation grade II, III, IV area decreased, by 7.32km^2, 13.88km^2, 19.32km^2, respectively (Table 5).

From the perspective of space, the change of integrity protection evaluation of Shibing and Libo–Huanjiang karst heritage site is mainly distributed in the buffer zone, and the transformation of heritage site is small. In conclusion, the integrity of the Shibing and Libo–Huanjiang karst heritage site was better protected from 2015 to 2020, indicating that the implementation of a series of heritage site conservation management measures has played a good role in protecting the integrity of the Shibing and Libo–Huanjiang karst.

Evaluation of sustainable development of agroforestry in the buffer zone

This paper calculates the buffer zone agroforestry sustainability development index of Shibing and Libo–Huanjiang karst mainly by taking the administrative villages developing agroforestry as the evaluation unit. We obtained the weights of each indicator of the two major systems in the five villages of Shibing karst and the four villages of the Libo–Huanjiang karst using the entropy method. We applied the linear weighting method to calculate the comprehensive evaluation indexes of agroforestry in the buffer zone.

Shibing karst villages have little change in agroforestry composite development, and the overall change in the evaluation indicators of each village shows an upward trend. (Fig. 7). In 2020, the comprehensive evaluation value of each village was higher than that in 2015. Among them, the highest total evaluation value of agroforestry development is Baiduo village, whose total evaluation value increased from 0.5006 to 0.6614 from 2015 to 2020, followed by Shijiawan village, whose total evaluation

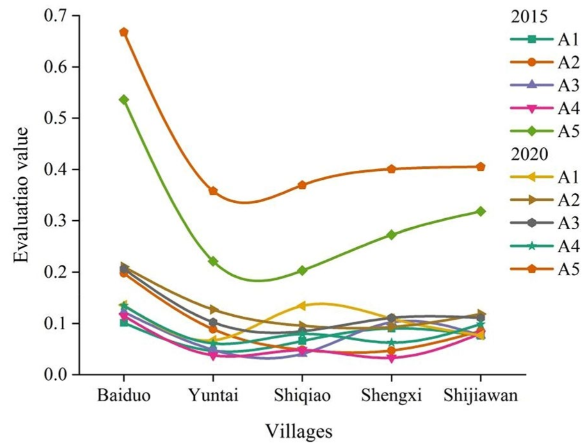

Fig. 7 Evaluation indicators and the comprehensive evaluation value of agroforestry sustainability in the buffer zone of Shibing karst in 2015–2020

value of agroforestry increased from 0.3182 to 0.4050 from 2015 to 2020. However, the comprehensive evaluation indexes of agroforestry development in Yuntai, Shiqiao and Shengxi villages is lower than Baiduo and Shijiawan villages. Although the comprehensive evaluation indexes of agroforestry development in Yuntai, Shiqiao, and Shengxi Villages are lower than that in Baiduo and Shijiawan Villages, their comprehensive evaluation values show a yearly risen, indicating that the agroforestry development in Shibing karst is better in recent years.

In general, the changes in agroforestry development are similar in the four villages, and although there are fluctuations in the evaluation indicators of each village in each year, the overall trend was upward (Fig. 8). In 2020, the comprehensive evaluation value of each village was higher than that of 2015 due to the goal of "ecological village, education village, fruit rich village, tourism strong village" in recent years.

The ecological and social benefit index values of the four villages from 2015–2020 are higher than the economic benefit and development prospect index values, which are relatively lower. Still, they all show a steadily

Table 5 Integrity protection level and area ratio of Libo–Huanjiang karst in 2015–2020

Integrity Grades	2015		2020		2015–2020
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area changes (km^2)
I	3.16	0.37	1.64	0.19	− 1.52
II	18.24	2.16	10.92	1.29	− 7.32
III	26.83	3.17	12.95	1.53	− 13.88
VI	54.88	6.49	36.56	4.32	− 18.32
V	742.64	87.81	783.68	92.66	41.04

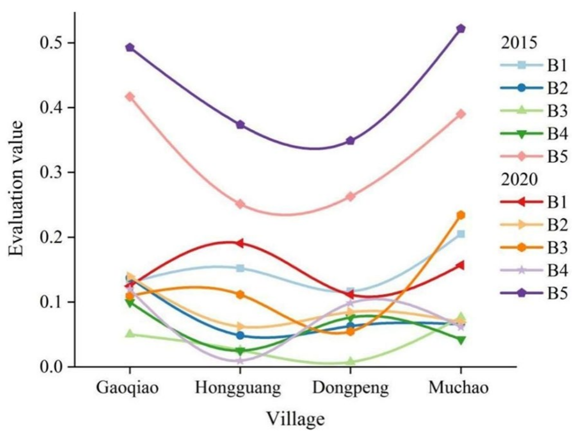

Fig. 8 Evaluation indicators and comprehensive evaluation value of agroforestry sustainability in the buffer zone of Libo–Huanjiang karst in 2015–2020

increasing trend. This indicates that the sustainability of agroforestry in the buffer zone of Libo–Huanjiang karst has gradually increased its ability to promote ecological and social benefits. From a practical point of view, implementing the conservation policy of Libo–Huanjiang karst has a good restorative effect on the ecological environment, and greatly improves the residents' well-being. In 2015–2020, the four subsystem indicators have been improved to different degrees from different perspectives, which also clearly shows that the role of each subsystem in promoting and influencing the sustainability level of agroforestry has been strengthened. Overall, the sustainable development of agroforestry in the buffer zone of Libo–Huanjiang karst has been at a reasonable and benign level in recent years.

Analysis of the degree of coupling coordination between heritage site integrity protection and buffer zone agroforestry

The coupling degree analysis

According to Eqs. 8–10, the coupling degree C and coupling coordination degree D of the heritage site integrity protection and the buffer zone agroforestry development of Shibing and Libo–Huanjiang karst were calculated and classified by setting the criteria. Generally, the coupling of heritage site integrity protection and the buffer zone agroforestry development of Shibing and Libo–Huanjiang karst was relatively stable from 2015 to 2020, indicating a high interaction between the two systems (Tables 6, 7).

In the spatial dimension, the coupling degree of Baiduo,Yuntai, Shiqiao, Shengxi, Shijawan villages of Shibing karst in 2015–2020 are high coupling (Fig. 9). The coupling degree of the four villages of Libo–Huanjiang karst was high in 2015–2020, both remaining above 0.8841, which is a high coupling (Fig. 10). This indicates that these nine villages' coupling degrees tend to develop orderly.

The coupled coordination degree analysis

The coupling coordination degree enables us to view the coupling relationship of the heritage site integrity protection and agroforestry development in the buffer zone,

Table 6 Coupling and coupling coordination degree of the heritage site integrity protection and the buffer zone agroforestry development of Shibing karst in 2015–2020

Villages	2015 (C)	Coupling type	2015 (D)	Coupling coordination relationship	2020 (C)	Coupling type	2020 (D)	Coupling coordination relationship
Baiduo	0.9988	High coupling	0.7505	Moderate coordination	0.9958	High coupling	0.8557	Good coordination
Yuntai	0.9522		0.5510	Reluctant coordination	0.9392		0.7153	Moderate coordination
Shiqiao	0.9339		0.5434	Reluctant coordination	0.9859		0.6612	Elementary coordination
Shengxi	0.9997		0.5292	Reluctant coordination	0.9895		0.6807	Elementary coordination
Shijiawan	0.8375		0.4151	Near-disorder	0.9760		0.5698	Reluctant coordination

Table 7 Coupling and coupling coordination degree of the heritage site integrity protection and the buffer zone agroforestry development of Libo–Huanjiang karst in 2015–2020

Village	2015 (C)	Coupling type	2015 (D)	Coupling coordination relationship	2015 (C)	Coupling type	2015 (D)	Coupling coordination relationship
Gaoqiao	0.9771	High coupling	0.7195	Moderate coordination	0.9777	High coupling	0.8035	Good coordination
Hongguang	0.9823		0.5513	Reluctant coordination	0.9769		0.6813	Elementary coordination
Dongpeng	0.8841		0.6605	Elementary coordination	0.9084		0.7381	Moderate coordination
Muchao	0.9989		0.6101	Elementary coordination	0.9960		0.7342	Moderate coordination

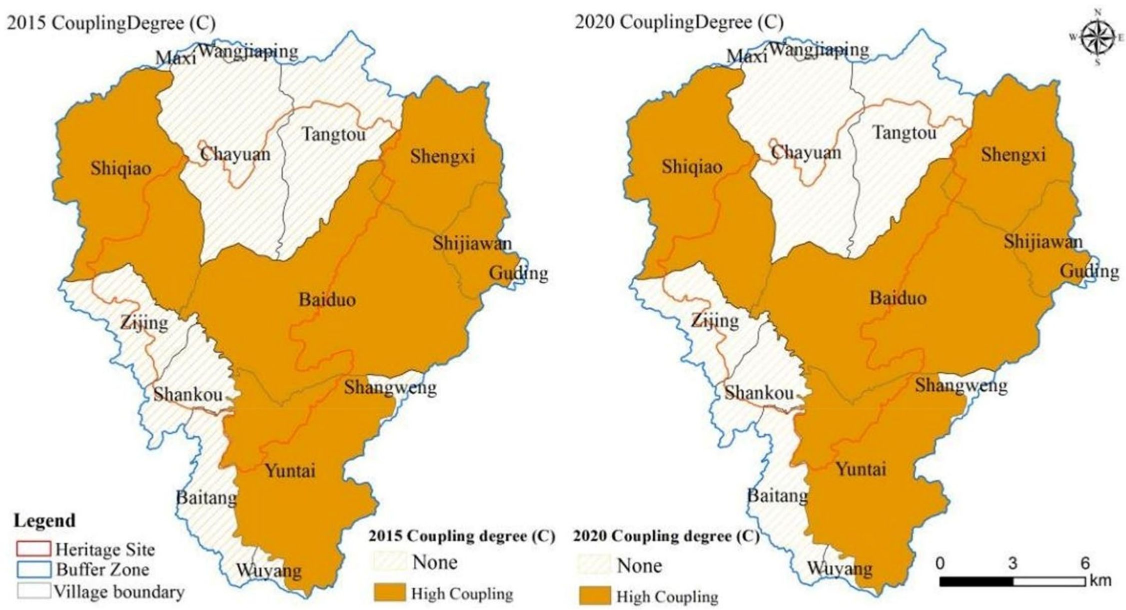

Fig. 9 The coupling degree of the heritage site integrity protection and agroforestry development in the buffer zone of Shibing karst in 2015–2020

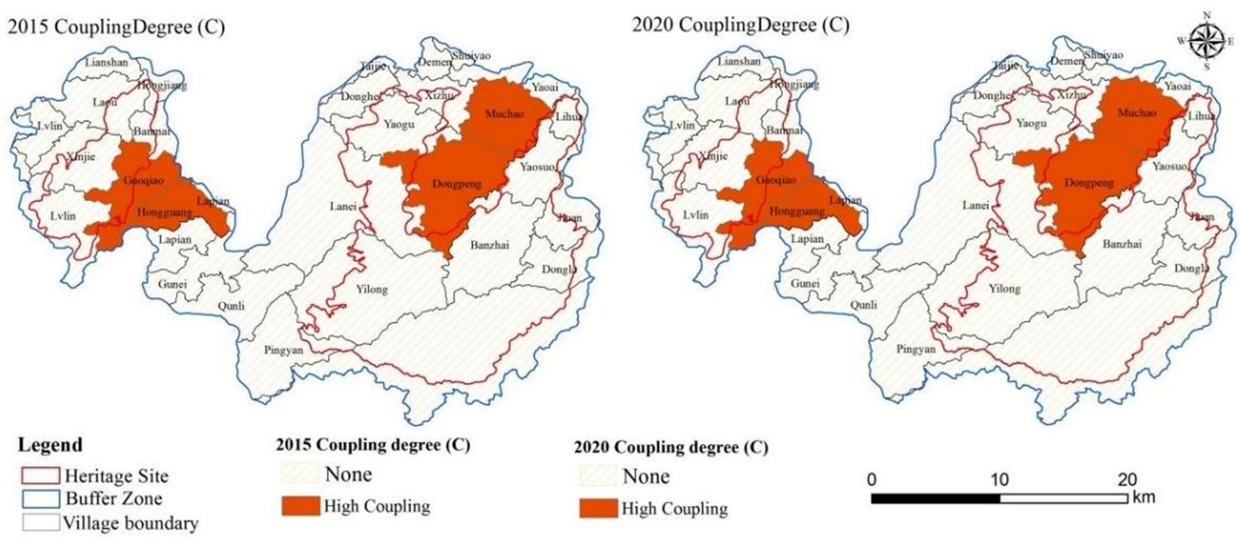

Fig. 10 The coupling degree of the heritage site integrity protection and agroforestry development in the buffer zone of Libo–Huanjiang karst in 2015–2020

which is more comprehensive and intuitive than a single coupling degree. We calculated the coupling coordination degree values of the whole region in the nine Shibing and Libo–Huanjiang karst villages from 2015 to 2020 using the coupling coordination degree model.

In the temporal dimension (Table 6), the coupled coordination degree of the heritage site integrity protection and the buffer zone agroforestry development of Shibing karst showed an increasing trend, with the mean value gradually increasing from 0.5578 in 2015 to 0.6965 in 2020. The coupling coordination degree values in 2015 range from 0.4151 to 0.7505, with the lowest and highest values occurring in Shijiawan and Baiduo villages, respectively, and the type of coupling coordination degree is on the verge of disorder and intermediate coordination. Compared with 2015, the coupling coordination degree value range of Shibing karst is 0.5698–0.8557 in 2020.

In the spatial dimension, the spatial distribution of the coupling coordination degree of two systems of Shibing karst from 2015 to 2020 has a specific stability (Fig. 11). The coupling coordination relationship gradually evolves from near-disorder, reluctant, and moderate coordination to elementary, moderate, and good coordination. The coupling coordination degree of the heritage site integrity protection and the buffer zone agroforestry development of Shibing karst can be roughly divided into four levels: on the verge of near-disorder (Shijiawan village), reluctant coordination (Yuntai, Shiqiao, and Shengxi villages), and moderate coordination (Baiduo village) in 2015; reluctant coordination (Shijiawan village), elementary coordination (Shiqiao and Shengxi villages), moderate coordination (Yuntai village), and good coordinated (Baiduo village) in 2020. This indicates that the heritage site integrity protection and the buffer zone agroforestry development of Shibing karst are developing in a benign direction, and the degree of correlation and interactive integration between the two systems is increasing.

In the temporal dimension, the coupling coordination degree between the two systems of Libo–Huanjiang karst is increasing, with the average value slowly increasing from 0.6353 in 2015 to 0.7392 in 2020 (Table 7). The range of coupling coordination degree in 2015 is 0.5513–0.7195, where the lowest and highest values occurred in Hongguang and Gaoqiao villages, respectively. And the type of coupling coordination is reluctant coordination and moderate coordination. In 2020, the level of coordinated development of the two systems of Libo–Huanjiang karst is significantly higher than that in 2015 (Fig. 12).

In the spatial dimension, the spatial distribution of the coupling coordination degree of the two systems of Libo–Huanjiang karst from 2015 to 2020 has some stability (Fig. 12). The coupled coordination degree between the two systems of Libo–Huanjiang karst can be roughly divided into three levels: reluctant coordination (Hongguang village), elementary coordination (Dongpeng and Muchao villages) and moderate coordination (Gaoqiao village) in 2015; and elementary coordination (Hongguang village) and reasonable coordination (Dongpeng and Muchao villages), good coordination (Gaoqiao village) in 2020. Overall, the coupling coordination degree of the four villages has increased,which indicates that the heritage site integrity protection and agroforestry development in the buffer zone of Libo–Huanjiang karst have a relationship of mutual promotion and common development.

In summary, the spatial and temporal distribution characteristics of the heritage site integrity protection coupling coordination and the buffer zone agroforestry development are relatively stable. The heritage site integrity protection and the buffer zone agroforestry development of Shibing and Libo–Huanjiang karst are an interconnected and mutually influential whole, and the coordinated relationship between them is of great

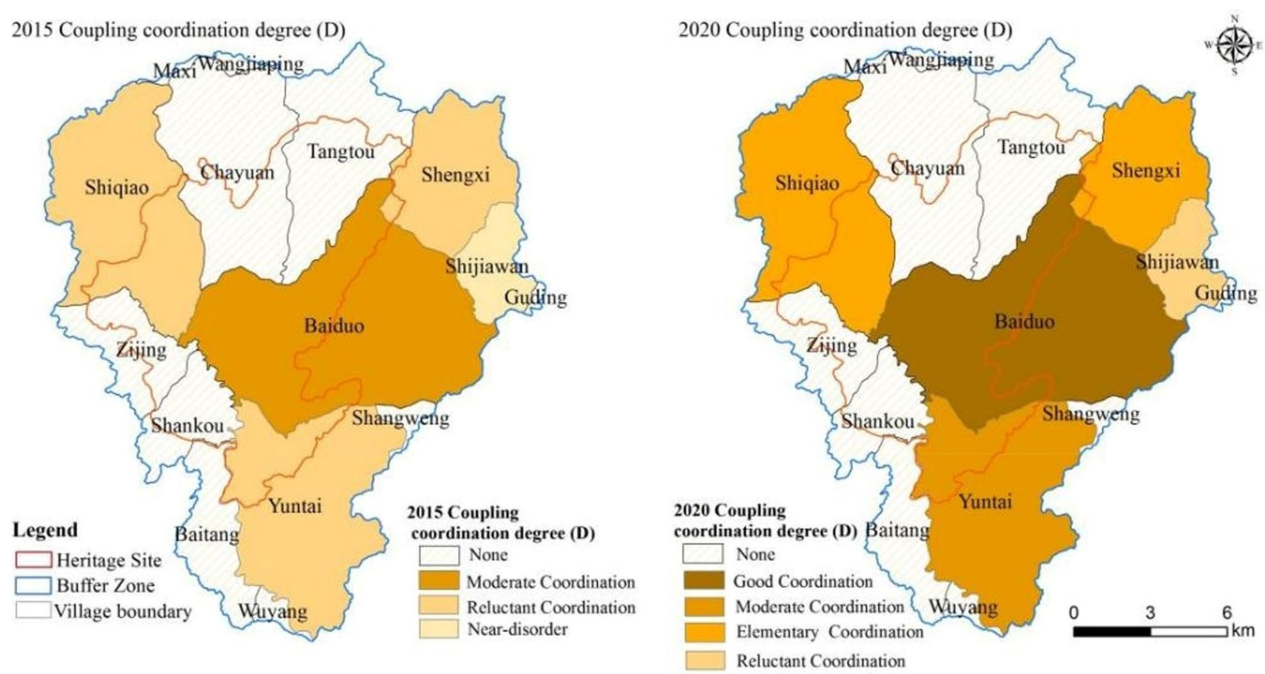

Fig. 11 The coupling coordination degree of the heritage site integrity protection and agroforestry development in the buffer zone of Shibing karst in 2015–2020

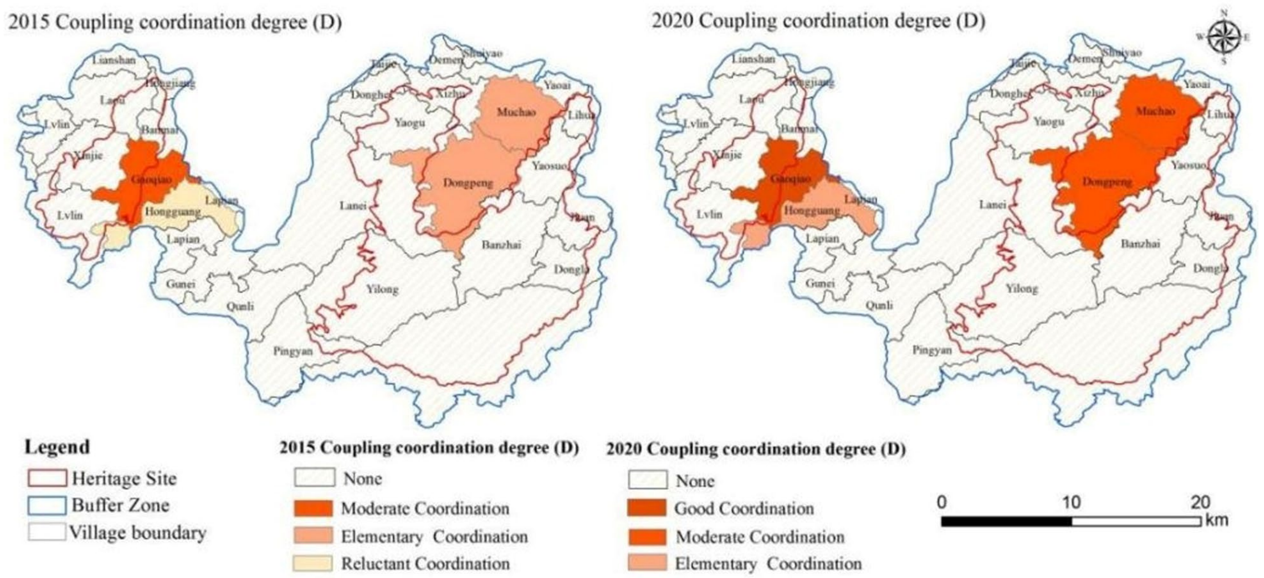

Fig. 12 The coupling coordination degree of the heritage site integrity protection and agroforestry development in the buffer zone of Libo–Huanjiang karst in 2015–2020

significance to promote the heritage site protection and the buffer zone sustainable development.

The relative degree of the heritage site integrity protection and the buffer zone agroforestry development

When the heritage site integrity protection and the buffer zone agroforestry development systems are analyzed, it can be found that the two systems are closely linked and interact with each other. The coupling degree C is used to indicate the degree of the close relationship between the two systems, and the coupling coordination degree D is an index value used to indicate the level of coupling coordination between the two systems, which cannot effectively predict the relative development degree between the two systems. Therefore, the ratio between the integrated development level of the heritage site integrity protection and the integrated development level of agroforestry in the buffer zone in different years is used as a tool to measure the relative development degree between the two, and assuming the ratio is P:

$$P = \frac{A_X}{B_X} \tag{11}$$

where P is the relative development degree of the heritage site integrity protection and the buffer zone agroforestry development, $P > 0$; A(x) is the combined level of the heritage site integrity protection; B(x) is the integrated level of the buffer zone agroforestry development.

By analyzing the relative development level P of the heritage site integrity protection and the buffer zone agroforestry development in each village of Shibing karst and Libo–Huanjiang karst. In 2015–2020, there were three main types of the heritage site integrity protection and the buffer zone agroforestry development in Shibing and Libo–Huanjiang karst villages, namely, the heritage site integrity protection lags, the buffer zone agroforestry development lags, and synchronous type of the heritage site integrity protection and the buffer zone agroforestry.

In 2015, the relative degree type of development of the two systems in Baiduo Village was synchronous development, and the relative degree type of development of the two systems in 2020 was agroforestry development lagging type. In 2015–2020, the relative degree type of development of the two systems in Yuntai and Shiqiao Villages were agroforestry development lagging type. In 2015, the relative degree type of development of the two systems in Shengxi Village was integrity protection lagging type, and the relative degree type of development of the two systems in 2020 was agroforestry development lagging type. In 2015–2020, the relative degree type of development of the two systems in Shijiawan Village was integrity protection lagging type (Table 8).

2015–2020, the relative degree type of development of the two systems in Gaoqiao, Hongguang, and Muzhao villages of Libo–Huanjiang karst is mainly the buffer zone agroforestry development lags. In 2015, the two systems' relative degree type of development in Dongpeng village was the heritage site integrity protection lags, and in 2020, the two systems' relative degree type of development was synchronous. (Table 9).

Table 8 The relative degree of the heritage site integrity protection and agroforestry development in the buffer zone of Libo–Huanjiang in 2015–2020

	Baiduo Village	Yuntai Village	Shiqiao Village	Shengxi Village	Shijiawan Village
2015	Synchronized development	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The heritage site integrity protection lags behind	The heritage site integrity protection lags behind
2020	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind

Table 9 The relative degree of the heritage site integrity protection and agroforestry development in the buffer zone of Libo–Huanjiang in 2015–2020

	Gaoqiao Village	Hongguang Village	Muchao Village	Dongpeng Village
2015	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The heritage site integrity protection lags behind
2020	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	The buffer zone agroforestry development lags behind	Synchronized development

In conclusion, this indicates that the integrity protection of Shibing and Libo–Huanjiang karst were well protected in 2015–2020, and the buffer zone agroforestry development needs to be further improved.

The heritage site integrity protection and the buffer zone agroforestry development regulation measures

The heritage site integrity protection regulation measures

The NWH site is a treasure endowed by nature to humankind, with typicality, uniqueness, non-renewability, and is of great significance tohumanity's history, reality, future. The NWH protection cannot be achieved without the participation and support of the residents in the buffer zone. Karst areas are affected by natural conditions and the interference of human socio-economic activities, and the ecosystem is very fragile, especially the WH karst site integrity protection is vulnerable to the influence of human activities. We found that the residents do not know well about the heritage site and buffer zone, basically they only know about the Yuntai, Daqikong, and Xaoqikong Scenic Area spots, and even less about the heritage site integrity protection. Humans inhabit the WH karst site buffer zone of Shibing and Libo–Huanjiang. The heritage site integrity protection must strengthen the protection awareness of the buffer zone residents, take actions to increase the publicity, education, security behavior of heritage protection policies, and improve the motivation of residents to participate in the protection behavior of the heritage site.

Firstly, training and publicity on heritage protection can be organized regularly in the village, so that everyone knows the difference between the heritage site and buffer zone and their protection attributes;

Secondly, encouraging the buffer zone residents to participate in the formulation of heritage protection policies and set up incentive rules to motivate them to join in and learn from heritage protection policies;

Finally, the economic income of buffer zone residents is driven by the protection and development policy of heritage site, such as tourism-driven employment for the residents, compensation measures for land acquisition, and incentives for environmental protection. It introduces ecologically sustainable industries to solve the resident's problems arising from the economic and security of the heritage site.

The buffer zone agroforestry development regulation measures

Agroforestry is one of the effective measures to achieve sustainable land use, and it is also necessary for the development of ecological protection. The agroforestry sustainable development benefits of Shibing and Libo–Huanjiang karst indirectly determine the protection degree of heritage site resources by residents. Strengthening the environmental and economic development of the buffer zone and promoting regional integration have become effective measures for the unbalanced development of Shibing and Libo–Huanjiang karst. Therefore, it is necessary to reasonably develop and utilize the natural ecological resources of Shibing and Libo–Huanjiang karst, optimize the industrial structure, increase the proportion of high-quality products, stimulate the maximum potential of the socio-economic benefits of agroforestry according to local conditions, and improve the market competitiveness of agroforestry.

Firstly, relying on agroforestry resources, it is combined with ecological tourism of the heritage site to realize the effective combination of tourism of the heritage site and the buffer zone agroforestry development model, driving the development of tourism and the sales of related agroforestry products.

Secondly, karst areas have a large population and generally have a relatively severs unbalanced contradiction between humans and land. As an ecologically sustainable industrial development model promoted in the buffer zone of Shibing and Libo–Huanjiang karst, agroforestry has good ecological and considerable economic and social benefits. Therefore, the government should strengthen the financial and fiscal support for the agroforestry development, guide the residents engaged in agroforestry development to learn the advanced processing and production technology of agroforestry products, expand the scale and strengthen the deep processing of agroforestry products, and improve their added value, to realize the upgrading of agroforestry industry and products.

Finally, agroforestry is an environmentally friendly and ecologically sustainable artificial ecosystem. Planting or raising two or more different individuals on the same land unit requires that agroforestry practitioners have extensive experience and relevant expertise in planting and farming. Thus, it is necessary to provide targeted training for agroforestry practitioners, continuously improve appropriate technologies according to the actual situation of agroforestry development in Shibing and Libo–Huanjiang karst, and guide residents to develop feasible agroforestry models based on other advanced agroforestry development technologies. In addition, it is necessary to transform agroforestry development technologies into simple and easy-to-operate technologies when promoting agroforestry.

Discussion

The NWH integrity emphasizes the integrity of natural heritage OUV elements and their surroundings [43–45]. Therefore, the relative integrity of the heritage site is used as a starting point and extended to the buffer zone to evaluate the heritage site integrity protection status. The indicators selection for evaluating the WH karst site integrity protection requires careful consideration of the OUV elements and the impacts generated by human activities in the buffer zone. Han [46] proposed an assessment method from the point of view of protecting heritage values. It measures the degree of outstanding landscape integrity under natural heritage sites' human and natural impact. Shi [36] evaluated the WH integrity of Xinjiang Tianshan from four aspects: landscape type function dominance、degree of landscape beauty, degradation of landscape type, landscape fragmentation. However, due to the difficulty of quantifying the integrity of geomorphic values, we don't select quantitative indicators to quantify the integrity of geomorphic values, but rather the integrity of aesthetic and geomorphic value embodiment, so the evaluation of the heritage site integrity protection may be less comprehensive. In addition, there is no further research to explore the specific evaluation criteria, management principles, and monitoring for the NWH integrity protection, and how to carry out a systematic and scientific evaluation of integrity protection. And how much change limits are acceptable for integrity protection have become significant issues of concern for NWH in the future [10].

Currently, most studies focus on only one or a few aspects of agroforestry systems, and rarely take an integrated and quantitative approach to examine the broader ecological, economic, and social benefits [47]. Sustainability is the greatest advantage of agroforestry, and most researchers tend to focus only on environmental benefits, while farmers are only concerned with immediate economic benefits and profits [31, 48]. Therefore, it is not easy to give full play to the overall advantages of agroforestry systems, and to objectively and comprehensively evaluate the comprehensive benefits of sustainability of agroforestry. Based on the existing relevant studies, make full use of their relevant fundamental theories and research results, etc. Establish a systematic, complete, scientific, and feasible comprehensive evaluation index system of agroforestry sustainability. And select an effective comprehensive evaluation method, which can conduct a thorough and objective evaluation of the sustainable development of ecological, social and economic benefits of agroforestry in different sites, different management objectives and different development stages. In order to give full play to the overall advantages of the agroforestry system and improve the comprehensive benefits of the agroforestry system [49].

Meanwhile, we also found that the residents consciousness of about the heritage integrity protection and buffer zone agroforestry coordinated development is weak. What's more, agroforestry industrial structure area layout scale is small, not high yield proportion, agroforestry products overall quality is not high, weak market competitiveness. Therefore, the future we should encourage the buffer zone residents to participate in heritage protection policy, through heritage protection and development of the buffer residents economic income measures for heritage protection and the buffer zone agroforestry development support.

The study showed that the heritage site integrity protection and the buffer zone agroforestry development have a high coupling coordination degree, consistent with Luo's coupling study [41] on conserving the WH karst site values and buffer zone agroforestry development. It shows that buffer zone agroforestry has a positive effect on heritage protection, which not only protects the living standard of buffer zone residents from being affected, improves the economic development of residents, but also protects the resources of the heritage from being destroyed. However, the heritage site integrity protection and the buffer zone agroforestry development systems are more complex, and the relationship between the two systems involves more complex and diverse elements. The ecological, social, economic development of the buffer zone increasingly interacts with heritage conservation. Therefore, to deeply analyze the coupling relationship between the two systems and multi-disciplinary intersection, multi-element coupling, multi-method combination and multi-data analysis are needed to promote the coupling and coordinated development.

Conclusions

This study takes the Shibing karst and Libo–Huanjiang karst as the study areas, aiming at the problems of a lack of research related to the WH site integrity protection and the evaluation of agroforestry development in the buffer zone, as well as the lack of synergy of them. Through the remote sensing images, landscape index, field survey data collection, elucidated the synergy relationship of the WH site integrity protection and agroforestry development in the buffer zone. Also, by the model methods of comprehensive index evaluation, coupling and coupling coordination degree, which proposed regulatory measures for the balanced development of the WH site integrity protection and agroforestry development in the buffer zone. The main conclusions are as follows:

1. The heritage site integrity protection and buffer zone agroforestry development is better, and the buffer zone agroforestry development lags behind the heritage site integrity protection;
2. The heritage site integrity protection and buffer zone agroforestry development have a high coupling degree and good coupling coordination, and the heritage site integrity protection and buffer zone agroforestry development is an interconnected and influential whole, the coupling and coordination between the two is developing in a positive direction;
3. The heritage site integrity protection is closely related to the buffer zone agroforestry development. Taking ecological sustainability as the criterion, promoting the balanced development of the heritage site integrity protection and the buffer zone agroforestry development by strengthening education and publicity of heritage protection policies for buffer zone residents, adjusting the industrial structure of agroforestry, relieving residents' economic pressure, and transforming traditional planting methods and other regulatory measures.

In conclusion, in the process of protection and development of Shibing and Libo–Huanjiang karst, the spatial coupling relationship of the heritage site integrity protection and agroforestry development in the buffer zone should be fully emphasized to achieve their synergy and sustainable development.

Abbreviations

NWH	Natural World Heritage
WH	World Heritage
SCK	South China Karst
OUV	Outstanding Universal Value
WHL	World Heritage List
WHC	World Heritage Convention

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Author contributions

KNX proposed the main innovation points of the paper and the construction of the overall writing framework, and wrote part of the content. DC carried out data collection and processing, and main writing work. KNX and JZ reviewed the whole text and made comments and suggestions to improve it. XYG and NZ edited parts of the manuscript. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

Data sharing is not applicable to this manuscript as no datasets were generated or analyzed.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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