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Enhancing Sustainability through Ecosystem Services Evaluation: A Case Study of the Mulberry-Dyke and Fish-Pond System in Digang Village

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Abstract: This research centers on the Mulberry-Dyke and Fish-Pond System in Digang Village, Huzhou, exemplifying the traditional cyclic agricultural models of China. The study's objective is to evaluate its integral value concerning agricultural production, ecological environment, and heritage conservation. Employing the Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methodologies, we developed a comprehensive evaluation framework comprising 8 dimensions and 29 factors, aimed at assessing the provisioning, regulating, and cultural services of this ecosystem. The findings indicate a robust performance of the ecosystem services in Digang Village's Mulberry-Dyke and Fish-Pond System, with cultural services significantly standing out. In contrast, the regulating services appeared relatively weaker, pinpointing shortcomings in mulberry land management, while the provisioning services demonstrated substantial strength. These insights are pivotal for comprehending the system's ecosystem service values, highlighting areas for managerial improvements, and guiding future assessment and management strategies. This study contributes theoretical insights and empirical experiences for future evaluations of the Mulberry-Dyke and Fish-Pond System's ecosystem services.

Keywords: analytical hierarchy process; fuzzy comprehensive evaluation; mulberry-dyke and fish-pond system; ecosystem service evaluation

1. Introduction

The Mulberry-Dyke and Fish-Pond System represents a distinctive agroecosystem in China, renowned globally for its pond mud fertilizing mulberry, mulberry leaves nurturing silkworms, silkworm sand feeding fish, and fish manure fertilizing mud—the essence of a highly productive agricultural model [1]. In the face of technological progress, contemporary agricultural practices are increasingly dominated by mechanization and facility implementation [2,3]. This shift has resulted in enhanced agricultural efficiency and expanded operations, making significant contributions to global food production and supply chain development [4]. However, the modern agricultural model, prioritizing economic efficiency, often comes at the cost of substantial energy and resource consumption, posing potential threats to the ecological balance [5,6]. In contrast, traditional circular agriculture not only prioritizes economic gains but also considers ecological preservation and local cultural heritage [7]. The sustainability and ecological principles inherent in this traditional model offer valuable insights for steering the modern agricultural model toward sustainable development.

Ecosystem Services (ES) refer to the advantages that humans obtain from ecosystems, ultimately striving for sustainable human well-being [8,9]. As outlined by the United Nations Millennium Ecosystem Assessment (MA), these services are classified into Provisioning Ecosystem Services (PES), Regulating Ecosystem Services (RES), Cultural Services (CES), and Supporting Ecosystem Services (SES) [10]. The Mulberry-Dyke and Fish-Pond System, as a representative of Chinese agricultural culture, holds significant value across diverse domains, including agricultural

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production, ecological environment, and cultural heritage preservation. Evaluating the ecosystem services of Mulberry-Dyke and Fish-Pond System provides insights into their comprehensive benefits, encompassing food production, ecosystem regulation, and cultural heritage contributions. This assessment aids management and decision-makers in formulating more scientific and rational agricultural strategies, fostering economically, socially, and environmentally sustainable agricultural development.

Currently, methods for assessing ecosystem services are broadly categorized into two types: valuation-based and material-based assessments [11-13]. Valuation-based assessments primarily focus on providing decision-makers with management strategies and grounds for evaluating market values of services, whereas material-based assessments concentrate on investigating the mechanisms behind the formation of ecosystem services. In existing research on the ecosystem services of the Mulberry-Dyke and Fish-Pond System, scholars have employed these two assessment methods. For instance, using the contingent valuation method, a study assessed the value of nine ecosystem services of the Mulberry-Dyke and Fish-Pond System, revealing that its overall service value exceeds that of separate mulberry gardens and fish ponds combined [14]. Additionally, the emergy (embodied energy) method was used to compare different agricultural ecological engineering models of the system [15], production models from various periods [16], and the differences between the dyke-pond system and traditional agriculture [17], thus evaluating the sustainability of the Mulberry-Dyke and Fish-Pond System model. However, these studies have not comprehensively assessed the overall benefits of the system in terms of production, ecology, and culture, necessitating further in-depth research to fully reveal its performance in these areas.

With the aim of addressing the inadequacies in Mulberry-Dyke and Fish-Pond System ecosystem service evaluation methods and indices, this study focused on Digang Village, situated in the core protection area of Mulberry-Dyke and Fish-Pond System in Huzhou. The study established an ecosystem service evaluation system for Mulberry-Dyke and Fish-Pond System based on the PES, RES, and CES categories according to the MA classification of ES. Employing the Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methodologies, the study tackled the fuzzy and uncertain aspects in the evaluation process. This comprehensive approach was employed to assess the ecosystem services of Mulberry-Dyke and Fish-Pond System in Digang Village, enabling a judgment on these services. The primary objectives include providing managers with effective strategies, evaluating the ecosystem services of mulberry ponds in the village, and contributing to the existing research on Mulberry-Dyke and Fish-Pond System ecosystem services through assessment.

2. Materials and Methods

2.1. Study Area

The Mulberry-Dyke and Fish-Pond System in Huzhou, Zhejiang Province (37°12′18″N and 120°17′40″E) is situated in the plains on the southern shore of Lake Taihu, characterized by a subtropical climate with an average annual temperature ranging from 17.8°C to 18.2°C and an annual precipitation of 1,348-1,723 mm. Designated as a Globally Important Agricultural Heritage Systems (GIAHS) in 2017. Digang Village, located within Nanxun District of Huzhou, is an important monitoring site for the Mulberry-Dyke and Fish-Pond System, with a total area of about 643 hm^2, consisting of arable land, garden land, forest land, grassland waters and water facilities land, construction land and other land, of which the area of the Mulberry-Dyke and Fish-Pond System is about 220 hm^2, and the main agricultural activities in the village are freshwater fish farming and mulberry silkworm cultivation. The most important agricultural species in the system include 2 types of silkworms, 4 types of mulberry trees, 7 types of fish species, and 3 types of fruits and vegetables, with a household population of about 1,141, of which the number of farmers providing heritage tourism services is about 280, and a per capita income of 6,500 yuan for farmers operating agro-cultural heritage. The village has a core conservation area for mulberry-based fish ponds, which covers an area of about 66 hm^2, of which the mulberry orchards cover an area of about 23-25 hm^2 and

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the fish ponds cover an area of about 33-35 hm². The study is based on the village of Dikgang and the core conservation area within the village within this scope.

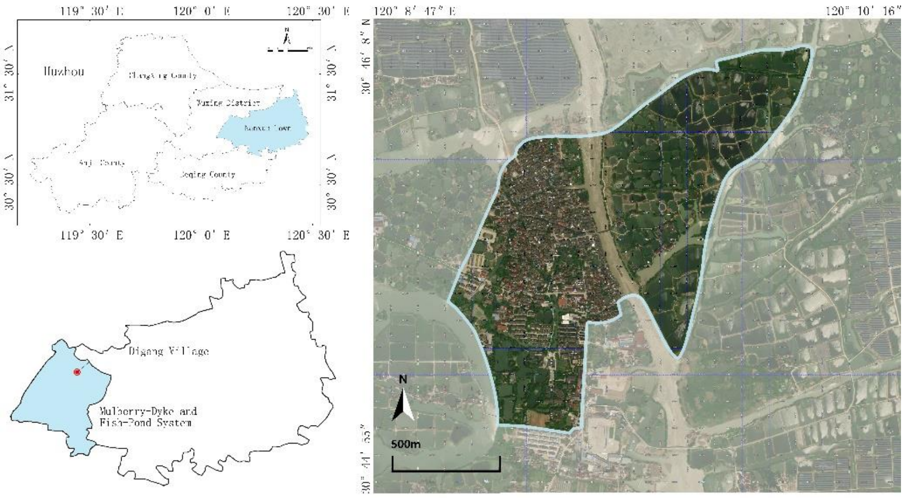

Figure 1. Location of the core conservation area of Mulberry-Dyke and Fish-Pond System in Digang Village, Huzhou, China.

2.2. Methodology and Data

2.2.1. Modeling the Valuation of ES

A scientific evaluation index system serves as the prerequisite and foundation for the effective evaluation of ecosystem services in Mulberry-Dyke and Fish-Pond System [18]. In the classification of ES by the MA [10], Provisioning Ecosystem Services (PES) encompass services produced or provided by ecosystems, such as food, fiber, genetic resources, etc. RES are benefits derived from the regulating function of ecosystem processes, including the regulation of atmospheric quality, climate, and the environment, etc. CES refer to non-material benefits obtained from ecosystems. Additionally, supporting services represent a function of ecosystems necessary for the provision of other services. In the context of Mulberry-Dyke and Fish-Pond System, PES, RES, and CES were specifically selected to construct a comprehensive ecosystem service evaluation system.

Building upon existing literature [19-25], results of discussions with 4 experts in ecology, and an assessment of the operational status of Mulberry-Dyke and Fish-Pond System, the evaluation index system was designed. Given the significance of mulberry harvesting and fish farming densities in these fishponds [26-28], the production of mulberries and fish was chosen to characterize the PES. Differences in temperature and humidity between Mulberry-Dyke and Fish-Pond System and downtown Huzhou City, as well as the air quality index of Mulberry-Dyke and Fish-Pond System, were used to characterize the climate regulation value of the RES, and its basal environmental regulation capacity was flanked by the pesticide and fertilizer use in Mulberry-Dyke and Fish-Pond System, thus characterizing the basal environmental regulation value of the RES [29-32]. CES were characterized with four aspects: aesthetics, education, leisure and entertainment, and cultural heritage [33, 34]. The finalized evaluation index system comprises one objective, three guidelines, 8 indicators, and 29 factors. The specific framework of the index system is detailed in Table 1 below.

Table 1. Ecosystem Service Assessment of Mulberry-Dyke and Fish-Pond System.

Target Layer	Criterion Layer	Index Layer	Factor Layer
A Ecosystem service	B1	C1 Mulberry land production value	D1 Mulberry leaf production
			D2 Mulberry fruit production

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assessment of Mulberry-Dyke and Fish-Pond System	Provisioning ecosystem services	C2 Fishpond production value	D3 Conventional fish farming production D4 Ecological fish farming production
	B2 Regulating ecosystem services	C3 Basal environment regulation value	D5 Fertilizer application intensity D6 Pesticide application intensity
		C4 Climate regulation value	D7 Relative humidity adjustment range D8 Average temperature regulation D9 Air quality index
	B3 Culture ecosystem services	C5 Aesthetics value	D10 Plant landscape richness D11 Seasonal changes in the landscape D12 Overall harmony D13 Water clarity D14 Leveling and hardening of road surface
		C6 Education value	D15 Fish and mulberry culture education D16 Humanistic tradition D17 Cultural propaganda and exhibition D18 Religious culture
		C7 Leisure and entertainment value	D19 Location conditions D20 Sanitary conditions D21 Tourism infrastructure D22 Agricultural Diversity Experience D23 Experience the diversity of tourism products D24 Visual and psychological perception
		C8 Cultural heritage value	D25 Village architectural style D26 Village traditional customs D27 Ancient bridges and other historical and cultural features D28 Food culture characteristics D29 Fish and mulberry culture characteristics

2.2.2. AHP-FCE Based Ecosystem Service Evaluation model For Mulberry-Dyke and Fish-Pond System

The evaluation model consists of two main parts. First, the Analytical Hierarchy Process (AHP) method is employed to establish the weights for the indicators within the ecosystem service evaluation system for Mulberry-Dyke and Fish-Pond System. Then, the multilevel Fuzzy Comprehensive Evaluation (FCE) method is applied to conduct a comprehensive assessment of the ecosystem services of Mulberry-Dyke and Fish-Pond System. The integrated AHP-FCE evaluation model is outlined as follows:

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The evaluation model is divided into 2 parts, firstly, the AHP method is used to determine the weights of the indicators of the ecosystem service evaluation system of Mulberry-Dyke and Fish-Pond System, based on which the multilevel FCE method is used for the comprehensive evaluation of the ecosystem services of Mulberry-Dyke and Fish-Pond System. The evaluation model integrated AHP-FCE method is as follows:

(1) Establishment of evaluation factor domain and evaluation criteria

Establishment of the evaluation factor domain V for ecosystem services in Mulberry-Dyke and Fish-Pond Systems, divided into 5 Levels.

Table 2. The evaluation criteria for the Mulberry-Dyke and Fish-Pond System ecosystem services.

Level	Score range	Definition
I	4~5	High ecosystem services
II	3~4	Relatively high ecosystem services
III	2~3	General ecosystem services
IV	1~2	Relatively low ecosystem services
V	0~1	Low ecosystem services

Table 3. Quantitative Factor Assessment Criteria.

Criterion Layer	Index Layer	Factor Layer	Level				
			5	4	3	2	1
B1 Provisioning ecosystem services	C1 Mulberry land production value	D1（t/hm²）Mulberry leaf production	≥75.00	52.50~75.00	45.00~52.50	37.50~45.00	≤37.50
		D2（t/hm²）Mulberry fruit production	≥75.00	60.00~75.00	42.00~60.00	36.00~42.00	≤36.00
	C2 Fishpond production value	D3（t/hm²）Conventional fish farming production	≥90.00	67.50~90.00	45.00~67.50	22.50~45.00	≤22.50
		D4（t/hm²）Ecological fish farming production	≥45.00	33.80~45.00	22.50~33.80	11.3~22.50	≤11.30

B2 Regulating ecosystem services	C3 Basal environment regulation value	D5（kg/hm^2） Fertilizer application intensity	＜200.00	200.00~250.00	250.00~350.00	350.00~450.00	＞450.00
		D6（kg/hm^2） Pesticide application intensity	＜2.50	2.50~3.00	3.00~4.00	4.00~4.50	＞4.50
	C4 Climate regulation value	D7 （%） Relative humidity adjustment range	＞4.00	3.00~4.00	2.00~3.00	1.00~2.00	＜1.00
		D8 （℃） Average temperature regulation	＞4.00	3.00~4.00	2.00~3.00	1.00~2.00	＜1.00
		D9 Air quality index	＜50.00	50.00~100.00	100.00~150.00	150.00~200.00	＞200.00

Based on the aforementioned evaluation factor domain V, in conjunction with relevant criteria and references [35-38], the quantitative factor evaluation standards were established. The data related to mulberry leaf production (D1), mulberry fruit production (D2), Conventional fish farming production (D3), ecological fish production (D4), as well as fertilizer and pesticide usage, were sourced from the Huzhou agricultural science and technology development center academician and expert workstation specializing in Mulberry-Dyke and Fish-Pond System. Additionally, the air quality index (D9) was determined based on China's "Ambient air quality standards" GB3095-2012.

Qualitative data is characterized by five levels of satisfaction (very familiar, quite familiar, moderately familiar, slightly familiar, unfamiliar) to represent the membership degree of evaluation indicators to the evaluation factor domain V.

Table 4. Qualitative Factor Definitions.

Criterion Layer	Index Layer	Factor Layer	Definition
B3 Culture ecosystem services	C5 Aesthetics value	D10 Plant landscape richness	Hierarchical sense of trees, shrubs, and ground cover vegetation; diversity of species.
		D11 Seasonal changes in the landscape	Seasonal changes in trees, shrubs, and ground cover vegetation, including both woody and herbaceous plants.
		D12 Overall harmony	The overall sense of harmony within the village, formed by the cultural

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		landscapes, streets, alleys, architecture, and vegetation within the village.
	D13 Water clarity	The condition of water bodies in the environment.
	D14 Leveling and hardening of road surface	Whether the road conditions are in accordance with the environment, including within the village and inside the Mulberry-Dyke and Fish-Pond System, with visual comfort as the criterion.
C6 Education value	D15 Fish and mulberry culture education	The educational significance or value brought by fish-mulberry culture and the research-oriented activities centered around it.
	D16 Humanistic tradition	The existing stories of prominent individuals, their spirit, and character within the village that possess propagational and educational significance.
	D17 Cultural propaganda and exhibition	The educational significance or value brought by the promotion and display of folk culture.
	D18 Religious culture propaganda	The spiritual connotations brought by the religious culture atmosphere, as well as the level of understanding and acceptance of it.
C7 Leisure and entertainment value	D19 Location conditions	The accessibility of the village's geographical location, transportation convenience, and natural environment.
	D20 Sanitary conditions	Environmental hygiene conditions.
	D21 Tourism infrastructure	Basic infrastructure including toilets, signage, parking spaces, medical service facilities, etc.
	D22 Agricultural Diversity Experience	Diverse experiences provided by agricultural products such as freshwater fish, mulberry leaf tea, fruits, rice, sesame oil, etc., based on the raw materials produced in Digang Village, which are either processed or directly sold.
	D23 Experience the diversity of tourism products	Satisfy diversified tourism needs by visiting Digang Village.
	D24 Visual and psychological perception	Experiences of visual and psychological sensations brought about by exploring Digang Village.
C8 Cultural heritage value	D25 Village architectural style	Whether the architectural style within the village conforms to the characteristics of the Jiangnan water town and rural farming.

	D26 Village Traditional customs	Whether traditional folk customs within the village are fully preserved, whether the atmosphere of folk customs is good, and whether they have distinctive features.
	D27 Ancient bridges and other historical and cultural features	The distinctiveness of cultural landscapes such as ancient bridges, celebrity memorial halls, and the scenic beauty of Nantiao.
	D28 Food culture characteristics	The distinctiveness of Di Gang cuisine, exemplified by the Chen family's dishes and local snacks.
	D29 Fish and mulberry culture characteristics	The distinctive features of the fish-mulberry culture.

(2) Determination of weight values

Applying the AHP method to determine the weights of each index. Comparisons are made pairwise among indicators at the same level to construct a judgment matrix. The normalization of weight values and weight vectors is then accomplished through relevant calculation formulas. The weight vector set is obtained through the verification steps [39,40].

(3) Constructing the affiliation matrix

Determine the membership degree of the evaluated object to the evaluation factor domain and obtain the fuzzy relationship matrix. In this study, the membership degree of quantitative data to the evaluation factor domain was determined through a trapezoidal function, and the membership degree of qualitative data to the evaluation factor domain was obtained through statistical analysis [41].

(4) Obtaining a composite score for the overall goal

Building on the aforementioned analysis, the overall goal composite score (F) was calculated using the weighted average method, expressed as $F = W \cdot R$.

Where W represents the weight vector set, and R represents the membership matrix.

2.2.3. Data

Table 5. Quantitative Data Acquisition.

Name	Unit	Data	Data sources
Mulberry land production	t/hm²	75.00	Huzhou Agricultural Science and Technology Development Center Academician and Expert Workstation
Mulberry fruit production	t/hm²	75.00	
Conventional fish farming production	t/hm²	90.00	
Ecological fish farming production	t/hm²	45.00	
Fertilizer consumption	t	4.00	
Pesticide consumption	CNY	34500.00	
Change in relative humidity (July-September 2022)	%	-1.42	Internal level meteorological information of Huzhou Municipal Meteorological Bureau
Change in average temperature (July-September 2022)	℃	-0.42	
AQI	/	64.90	http://www.weather.com.cn/

Data related to Mulberry-Dyke and Fish-Pond System in 2022 were collected through various methods, including interviews, questionnaires, field trips, and applications. The quantitative indicators were primarily sourced from the Huzhou agricultural science and technology development center academician and expert workstation. This data encompassed mulberry and fish production, as well as the quantities of fertilizers and pesticides used. Air quality index data were obtained from the weather network (http://www.weather.com.cn/). Qualitative indicators were gathered through a one-to-one questionnaire survey conducted with tourists and villagers engaged in activities at Digang Village Mulberry-Dyke and Fish-Pond System. A total of 109 questionnaires were initially collected, with 100 valid questionnaires selected after screening to exclude those completed in less than 2 minutes.

3. Results

3.1. AHP Weight for Each Indicator

Five experts and scholars specializing in ecosystem services research and planning and design of Digang Village were invited to provide judgments and weights. All tables passed the consistency test (see Appendix A), and the results are presented in Table 6.

At the guideline level (Table 6), it is evident that CES (B3) play a crucial role in influencing the overall ecosystem services of Mulberry-Dyke and Fish-Pond System, commanding a weight share of 0.51. Within CES (B3), the value of aesthetics, education, leisure and entertainment, and cultural heritage across four aspects contributes to this weight. Notably, the value of cultural heritage (C8) emerges as a significant influencing factor for CES (B3).

In the index layer (Table 6), the cultural heritage value (C8) holds the highest weight at 0.17, underscoring its significance as the primary manifestation of the ecosystem services of Mulberry-Dyke and Fish-Pond System. Notably, cultural heritage value (C8) is most profoundly influenced by factors such as food culture characteristics (D28) and fish and mulberry cultural characteristics (D29). Following closely, the fishpond production value (C1) is of considerable importance, with a weight share of 0.17. Its significance is primarily influenced by Ecological fish farming production (D4). Additionally, climate regulation value (C4), leisure and entertainment value (C7), and educational value (C6) exhibit comparable importance, with weight shares of 0.15, 0.13, and 0.12, respectively. Conversely, the remaining indicators—basal environmental regulation value (C3), mulberry land production value (C1), and aesthetic value (C5)—have weight shares of less than 0.0900. This suggests that the value contributed by the ecosystem services of Mulberry-Dyke and Fish-Pond System predominantly revolves around five aspects: cultural heritage, fishpond production, climate regulation, leisure and entertainment, and education. These indicators exert the most significant influence on the ecosystem services of Mulberry-Dyke and Fish-Pond System, warranting particular attention.

In the factor layer (Table 6), 8 indicators—Ecological fish farming production (D4), air quality index (D9), mulberry fruit production (D2), fish and mulberry culture education (D15), food culture characteristics (D28), Conventional fish farming production (D3), fish and mulberry culture characteristics (D29), and fertilizer application intensity (D5)—collectively account for a weight share of 0.51. Among these, Ecological fish farming production (D4) carries the highest weight at 0.1155, underscoring its paramount importance. This implies that these eight indicators are pivotal factors influencing the evaluation, and the ecosystem services of Mulberry-Dyke and Fish-Pond System emphasize production capacity and content related to fish and mulberry culture.

Table 6. Ecosystem Service Weight Table.

Criterion Layer	Normalized Weights	Indicator Layer	C-Layer Weight	Normalized Weights	Factor Layer	D-Layer Weight	Normalized Weights	Rank

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		C1	0.3556	0.0878	D1	0.2869	0.0262	14
B1	0.2572				D2	0.7131	0.0652	3
		C2	0.6444	0.1693	D3	0.3033	0.0503	6
					D4	0.6967	0.1155	1
		C3	0.3786	0.0884	D5	0.5000	0.0442	9
					D6	0.5000	0.0442	8
B2	0.2338				D7	0.2574	0.0374	10
		C4	0.6214	0.1454	D8	0.2568	0.0373	11
					D9	0.4859	0.0706	2
					D10	0.2478	0.0204	22
					D11	0.1330	0.0109	28
		C5	0.1616	0.0838	D12	0.2309	0.0190	23
					D13	0.1662	0.0137	26
					D14	0.2221	0.0183	24
					D15	0.4771	0.0567	4
					D16	0.2952	0.0351	12
		C6	0.2335	0.1226	D17	0.1512	0.0180	25
					D18	0.0766	0.0091	29
					D19	0.1606	0.0208	20
B3	0.5091				D20	0.1753	0.0228	17
					D21	0.1979	0.0257	15
		C7	0.2549	0.1320	D22	0.1314	0.0171	26
					D23	0.1679	0.0218	18
					D24	0.1668	0.0217	19
					D25	0.1500	0.0267	13
					D26	0.1402	0.0250	16
		C8	0.3500	0.1706	D27	0.1155	0.0206	21
					D28	0.3146	0.0561	5
					D29	0.2798	0.0498	7

3.2. Fuzzy Comprehensive Evaluation and Results

Refer to Appendix B for the calculation process. According to the principle of the maximum affiliation function of the FCE method, the affiliation degrees of ecosystem services of Mulberry-Dyke and Fish-Pond System are as follows: high level: 0.44, relatively high level: 0.32, general level: 0.10, relatively low level: 0.03, and low level: 0.11. The weighted average result is calculated as [0.44, 0.32, 0.10, 0.03, 0.11] × [5, 4, 3, 2, 1] = 3.97, indicating that the ecosystem services of Mulberry-Dyke and Fish-Pond System belong to the relatively high level. Multiply the membership degrees of each criterion, index, and factor by the normalized weights of each layer, as shown in Figure 2.

The evaluation results of the indicators at the normative level are presented in Figure 2a. Both PES (B1) and CES (B3) exhibit high performance, predominantly at the high and relatively high levels. In contrast, RES (B2) demonstrate a comparatively lower performance, mainly at the relatively low and low levels.

The evaluation results at the indicator and factor levels are depicted in Figure 2b,c. Notably, the four indicators related to the production value of mulberry land (C1) and fishponds (C2) excel,

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predominantly at the high level. This suggests that the production capacity of mulberry leaves, mulberry fruits, black carp, and eco-fish in Mulberry-Dyke and Fish-Pond System is robust. On the other hand, the basal environmental regulation value (C3) and climate regulation value (C4) exhibit lower performance, largely at the relatively low and low levels. This is primarily influenced by factors such as the intensity of pesticide application (D6), relative humidity regulation (D7), and average temperature regulation (D8). These results indicate deficiencies in pesticide use and the regulation of humidity and temperature in Mulberry-Dyke and Fish-Pond System. In contrast, the evaluation results for the four values of aesthetic value (C5), educational value (C6), leisure and entertainment value (C7), and cultural heritage value (C8) demonstrate a high degree of affiliation to high and relatively high, signifying high performance in these aspects. Among the five main values of ecosystem services in Mulberry-Dyke and Fish-Pond System, the climate regulation value (C4) is at the low level, indicating an important aspect that requires improvement. However, the top eight indicators in the factor hierarchy largely perform at the high or relatively high levels, suggesting a positive role in promoting the ecosystem services of Mulberry-Dyke and Fish-Pond System.

Table 7. Matrix of Quantitative Factor Memberships.

Factor Layer	Membership Matrix				
	5	4	3	2	1
D1 Mulberry leaf production	1.0000	0.0000	0.0000	0.0000	0.0000
D2 Mulberry fruit production	1.0000	0.0000	0.0000	0.0000	0.0000
D3 Conventional fish farming production	1.0000	0.0000	0.0000	0.0000	0.0000
D4 Ecological fish farming production	1.0000	0.0000	0.0000	0.0000	0.0000
D5 Fertilizer application intensity	0.6970	0.3030	0.0000	0.0000	0.0000
D6 Pesticide application intensity	0.0000	0.0000	0.0000	0.0000	1.0000
D7 Relative humidity adjustment range	0.0000	0.0000	0.0000	0.0000	1.0000
D8 Average temperature regulation	0.0000	0.0000	0.0000	0.4200	0.5800
D9 Air quality index	0.0000	0.7020	0.2980	0.0000	0.0000

Table 8. Matrix of Qualitative Factor Memberships.

Factor Layer	Membership Matrix				
	5	4	3	2	1
D10 Plant landscape richness	0.3600	0.5900	0.0500	0.0000	0.0000
D11 Seasonal changes in the landscape	0.3200	0.5900	0.0800	0.0000	0.0100
D12 Overall harmony	0.3100	0.5700	0.1000	0.0200	0.0000
D13 Water clarity	0.1100	0.5000	0.2900	0.0900	0.0100
D14 Leveling and hardening of road surface	0.2800	0.5100	0.1800	0.0300	0.0000
D15 Fish and mulberry culture education	0.3200	0.4700	0.1600	0.0400	0.0100
D16 Humanistic tradition	0.3500	0.5000	0.1100	0.0400	0.0000
D17 Cultural propaganda and exhibition	0.3000	0.4400	0.2200	0.0400	0.0000
D18 Religious culture propaganda	0.1200	0.2500	0.2500	0.3100	0.0700
D19 Location conditions	0.2800	0.4700	0.2200	0.0300	0.0000
D20 Sanitary conditions	0.3300	0.4900	0.1500	0.0200	0.0100
D21 Tourism infrastructure	0.2500	0.4900	0.2400	0.0200	0.0000
D22 Agricultural Diversity Experience	0.2100	0.6100	0.1800	0.0000	0.0000
D23 Experience the diversity of tourism products	0.1800	0.5900	0.2000	0.0300	0.0000

D24 Visual and psychological perception	0.3500	0.5300	0.0900	0.0300	0.0000
D25 Village architectural style	0.3700	0.4600	0.1600	0.0100	0.0000
D26 Village Traditional customs	0.3500	0.4900	0.1500	0.0100	0.0000
D27 Ancient bridges and other historical and cultural features	0.4200	0.4500	0.1200	0.0100	0.0000
D28 Food culture characteristics	0.3000	0.5100	0.1700	0.0200	0.0000
D29 Fish and mulberry culture characteristics	0.3000	0.5500	0.1400	0.0100	0.0000

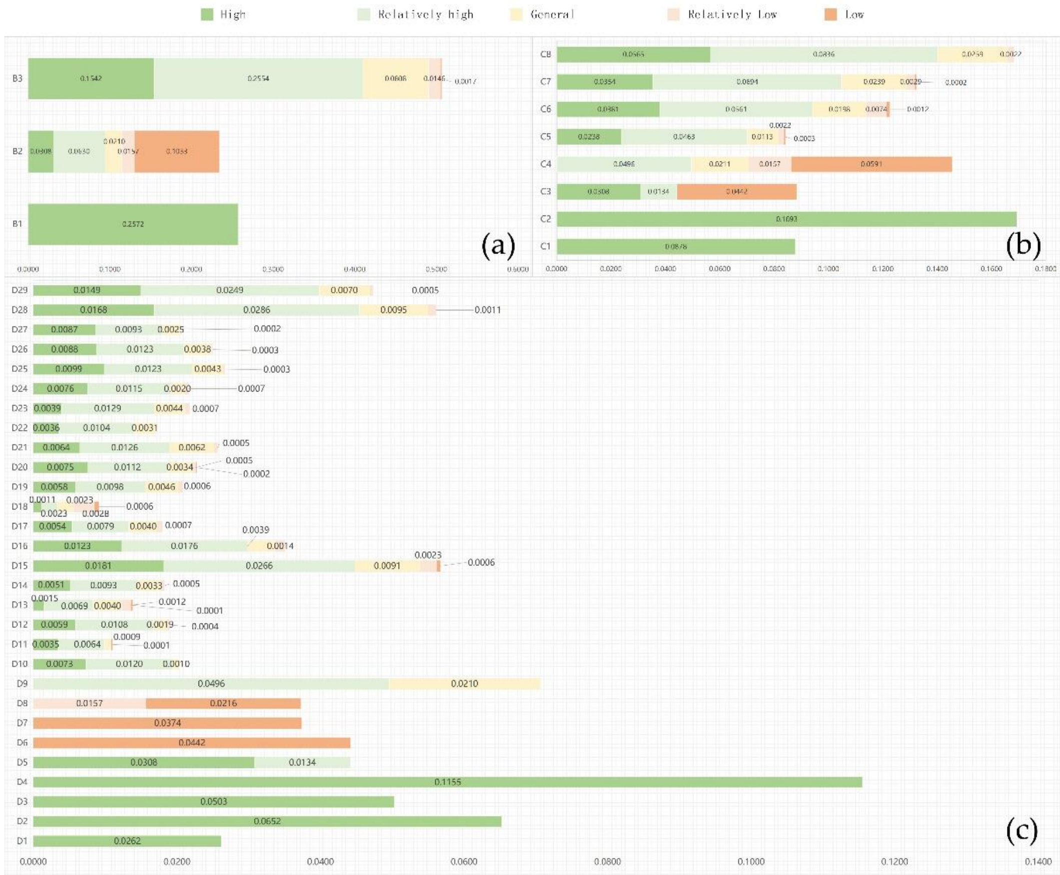

Figure 2. Assessment results for each layer. The values shown in the figure are the affiliation functions for each criterion, indicator, and factor layer.

4. Discussion

4.1. Optimized Management Strategy for Mulberry-Dyke and Fish-Pond System Based on AHP-FCE Approach

In our assessment of the Mulberry-Dyke and Fish-Pond System's ecosystem services, we discovered that the RES (B2) did not achieve high or moderately high levels. Furthermore, the distribution of membership degrees for these services revealed a pronounced bipolar trend, seemingly linked to the interplay among indicators D5 to D9. Specifically, indicators D5 and D6 reflected the growth conditions of mulberry trees to a certain extent, while the area and condition of the mulberry land directly influenced indicators D7, D8, and D9. Consequently, the outcomes for D5, D7, and D8 suggested deficiencies in the management of mulberry lands, underlining the necessity for enhanced professional support in this domain. Reduction and judicious use of pesticides could significantly bolster the regulating service capability of the system, thereby elevating the air quality index. On another front, CES (B3) emerged as a significant determinant of the system's ecosystem services. This underscores a growing public demand for recreational and cultural facets of the

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Mulberry-Dyke and Fish-Pond System. Notably, correlations between C5 and C7, as well as C6 and C8, were observed. Thus, reinforcing the key influencers in these aspects is expected to amplify the system's cultural service capacity. Strategic measures include diversifying plant arrangements, augmenting the overall cohesion of the system, enhancing tourism infrastructure, fortifying comprehensive environmental management, and intensively exploring the cultural and historical essence of fish and mulberry practices, along with promoting their unique gastronomical and cultural attributes. Moreover, the factor layer for B3 predominantly concentrated at a higher level, with a minority at high and average levels, potentially reflecting the evaluators' ambiguity and unclear understanding of related issues. Therefore, contrasting high and average level numerical differences could be more indicative, possibly unveiling divergences in opinions about indicator quality. Hence, indicators such as D13, D18, D19, D21, D22, and D23 merit close attention.

When exploring ecosystem services in multifunctional landscapes such as Sankey's fishponds, we must consider the multifunctionality between services and their trade-offs. According to the existing literature [42-44], ecosystem services are not always mutually reinforcing, but may be mutually constraining in some cases. Therefore, when planning, constructing and managing Mulberry-Dyke and Fish-Pond System, we should not simply seek to maximize a single service, but need to consider the balance among services in an integrated manner. The current assessment suggests that there may be some trade-offs between regulating services and provisioning and cultural services. In particular, it is foreseen that continued enhancement of cultural services will contribute to the diversification of the landscape of Mulberry-Dyke and Fish-Pond System, the enrichment of recreational facilities, and the improvement of public spaces. However, such changes may also lead to over-intervention in the environment of the Mulberry-Dyke and Fish-Pond System and consequently management neglect in the maintenance of vegetation and water bodies, thus affecting the effectiveness of regulating services. In the future management of Mulberry-Dyke and Fish-Pond System, we need to weigh the relationship between its ecological benefits and management costs among services.

4.2. Effectiveness of the AHP-FCE Method for Ecosystem Service Assessment in Mulberry-Dyke and Fish-Pond System

Relative to existing modeling approaches like InVEST and IMAGE, renowned for their efficacy in large-scale ecosystem service evaluations, these technologies adopt a modular design and scenario-based data input. They are adept at simulating and forecasting various future possibilities, furnishing quantitative outcomes for stakeholders balancing multiple ecosystem services [45,46]. Nonetheless, these models demand high data quality and volume, making them less suitable for addressing uncertainties, fuzziness, and data gaps in small-scale ecosystem service studies. Contrarily, the AHP-FCE method emerges as a more apt solution for such challenges, producing results that are more comprehensible and interpretable, thereby fostering societal engagement and the inclusion of stakeholder perspectives [47]. This is particularly evident in evaluations of ecosystems where cultural services are prominent, as the AHP-FCE method effectively mirrors public sentiments on the value of cultural services. Our findings underscore the pivotal role of cultural services within the ecosystem services of the Mulberry-Dyke and Fish-Pond System, concurrently highlighting managerial issues, resonating with prior research [14,48,49]. The increasing importance of the Mulberry-Dyke and Fish-Pond System's conservation and management is underscored by climate changes and land use transformations in the Nanxun District [48]. The AHP-FCE method facilitates the provision of a holistic evaluation indicator system and diagnostic techniques for the future progression of the system's ecosystem services. Moreover, this approach presents a viable resolution to the ambiguities encountered in ecosystem service assessments.

4.3. Future Improvement Directions of AHP-FCE Method for Ecosystem Service Valuation of Mulberry-Dyke and Fish-Pond System

This evaluation system still offers opportunities for refinement, and future improvements are suggested for enhancing the assessment of ecosystem services in Mulberry-Dyke and Fish-Pond

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System. Proposed directions for future enhancement include adjusting indicators based on local planning and development reports, scientific research findings, and selectively adding or reducing specific indicators to enhance the scientific rigor of the evaluation system. The monitoring system can be upgraded by accounting for the ratio of base ponds, tallying base crops, and subcategorizing aquatic crops cultivated in fish ponds. Additionally, the inclusion of quantitative indicators, such as monitoring soil and water quality, can enhance the overall robustness of the evaluation system. It is recommended to extend the temporal scope of data collection beyond the year 2022 to provide a more comprehensive understanding of the development status of Mulberry-Dyke and Fish-Pond System. Long-term research efforts will be crucial for gaining insights into the dynamic changes and trends within these ecosystems.

5. Conclusions

This study undertook a thorough evaluation of the ecosystem services of the Mulberry-Dyke and Fish-Pond System in Digang Village, Huzhou, utilizing the Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE). Our findings illuminate the paramount role of cultural services within the ecosystem services of the system, particularly emphasizing the substantial impact of cultural heritage values. In contrast, the underperformance of regulating services unveils gaps in mulberry land management and upkeep. These outcomes underscore the necessity to prioritize cultural heritage conservation and enhance regulating services in future management strategies.

The study not only proposes a scientifically robust method for assessing the ecosystem services of the Mulberry-Dyke and Fish-Pond System but also lays a solid foundation for decision-makers to devise more informed and rational management strategies. Additionally, by revealing the significance of cultural services and identifying the areas needing improvement in regulating services, this research charts new pathways for the sustainable development and ecological protection of the Mulberry-Dyke and Fish-Pond System. These findings hold substantial relevance for fostering the sustainable evolution of agricultural ecosystems in economic, social, and environmental dimensions.

Appendix A

Table A1. A-B Judgment Matrix and Weights.

Ecosystem Service Assessment of Mulberry-Dyke and Fish-Pond System	Provisioning Ecosystem Services B1	Regulating Ecosystem Services B2	Culture Ecosystem Services B3	Normalized Weights
Provisioning ecosystem services B1	1	1	1/2	0.2247
Regulating ecosystem services B2	1	1	1/5	0.1655
Culture ecosystem services B3	2	5	1	0.6098
$\lambda_{max} = 3.0940$	CI = 0.0470	RI = 0.5200		∑=1

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CR = 0.9040	Satisfying the consistency test

Table A2. Weight Table of Index layer in Provisioning Ecosystem Services B1.

Provisioning Ecosystem Services B1	Mulberry land Production Value C1	Fishpond Production Value C2	Normalized Weights
Mulberry land production value C1	1	1	0.5000
Fishpond production value C2	1	1	0.5000
λ_{max} = 2.0000	CI = 0.0000	RI = 0.0000	∑=1
CR = 0.0000	Satisfying the consistency test		

Table A3. Factor Layer Weights in Provisioning Ecosystem Services B1.

Criterion Layer	Index Layer	Factor Layer	Factor Layer Weight Coefficient
Provisioning ecosystem services B1	Mulberry land production value C1	Mulberry leaf production D1	0.5000
		Mulberry fruit production D2	0.5000
	Fishpond production value C2	Conventional fish farming production D3	0.5000
		Ecological fish farming production D4	0.5000

Appendix B

$$C1\text{Mulberry land production value} = w_i \cdot R\text{Mulberry land production value} = (0.2869, 0.7131)\begin{vmatrix} 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{vmatrix} = (1.0000, 0.0000, 0.0000, 0.0000, 0.0000) \quad (1)$$

$$C2\text{Fishpond production value} = w_i \cdot R\text{Fishpond production value} = (0.3033, 0.6967)\begin{vmatrix} 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{vmatrix} = (1.0000, 0.0000, 0.0000, 0.0000, 0.0000) \quad (2)$$

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$$C3\text{Basal environment regulation value} = w_i \cdot R\text{Basal environment regulation value}$$
$$= (0.5000,\ 0.5000)\begin{vmatrix} 0.6970 & 0.3030 & 0.0000 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{vmatrix}$$
$$= (0.3485,\ 0.1515,\ 0.0000,\ 0.0000,\ 0.5000) \quad (3)$$

$$C4\text{Climate regulation value} = w_i \cdot R\text{Climate regulation value}$$
$$= (0.2574,\ 0.2568,\ 0.4859)\begin{vmatrix} 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \\ 0.0000 & 0.0000 & 0.0000 & 0.4200 & 0.5800 \\ 0.0000 & 0.7000 & 0.3000 & 0.0000 & 0.0000 \end{vmatrix}$$
$$= (0.0000,\ 0.3411,\ 0.1448,\ 0.1078,\ 0.4063) \quad (4)$$

$$C5\text{Aesthetics value} = w_i \cdot R\text{Aesthetics value}$$
$$= \begin{pmatrix} 0.2478 \\ 0.1330 \\ 0.2309 \\ 0.1664 \\ 0.2221 \end{pmatrix}^T \begin{vmatrix} 0.3600 & 0.5900 & 0.0500 & 0.0000 & 0.0000 \\ 0.3200 & 0.5900 & 0.0800 & 0.0000 & 0.0100 \\ 0.3100 & 0.5700 & 0.1000 & 0.0200 & 0.0000 \\ 0.1100 & 0.5000 & 0.2900 & 0.0900 & 0.0100 \\ 0.2800 & 0.5100 & 0.1800 & 0.0300 & 0.0000 \end{vmatrix}$$
$$= (0.2838,\ 0.5526,\ 0.1343,\ 0.0262,\ 0.0030) \quad (5)$$

$$C6\text{Education value} = w_i \cdot R\text{Education value}$$
$$= \begin{pmatrix} 0.4771 \\ 0.2952 \\ 0.1512 \\ 0.7656 \end{pmatrix}^T \begin{vmatrix} 0.3200 & 0.4700 & 0.1600 & 0.0400 & 0.0100 \\ 0.3500 & 0.5000 & 0.1100 & 0.0400 & 0.0000 \\ 0.3000 & 0.4400 & 0.2200 & 0.0400 & 0.0000 \\ 0.1200 & 0.2500 & 0.2500 & 0.3100 & 0.0700 \end{vmatrix}$$
$$= (0.3105,\ 0.4575,\ 0.1612,\ 0.0607,\ 0.0101) \quad (6)$$

$$C7\text{Leisure and entertainment value} = w_i \cdot R\text{Leisure and entertainment value}$$
$$= \begin{pmatrix} 0.1606 \\ 0.1753 \\ 0.1979 \\ 0.1314 \\ 0.1679 \\ 0.1668 \end{pmatrix}^T \begin{vmatrix} 0.2800 & 0.4700 & 0.2200 & 0.0300 & 0.0000 \\ 0.3300 & 0.4900 & 0.1500 & 0.0200 & 0.0100 \\ 0.2500 & 0.4900 & 0.2400 & 0.0200 & 0.0000 \\ 0.2100 & 0.6100 & 0.1800 & 0.0000 & 0.0000 \\ 0.1800 & 0.5900 & 0.2000 & 0.0300 & 0.0000 \\ 0.3500 & 0.5300 & 0.1900 & 0.0300 & 0.0000 \end{vmatrix}$$
$$= (0.2685,\ 0.5260,\ 0.1814,\ 0.0223,\ 0.0018) \quad (7)$$

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$$C8\text{Cultural heritage value} = w_i \cdot R\text{Cultural heritage value}$$
$$= \begin{pmatrix} 0.1500 \\ 0.1402 \\ 0.1155 \\ 0.3146 \\ 0.2798 \end{pmatrix}^T \begin{vmatrix} 0.3700 & 0.4600 & 0.1600 & 0.0100 & 0.0000 \\ 0.3500 & 0.4900 & 0.1500 & 0.0100 & 0.0000 \\ 0.4200 & 0.4500 & 0.1200 & 0.0100 & 0.0000 \\ 0.3000 & 0.5100 & 0.1700 & 0.0200 & 0.0000 \\ 0.3000 & 0.5500 & 0.1400 & 0.0100 & 0.0000 \end{vmatrix}$$
$$= (0.3314，0.5040，0.1515，0.0131，0.0000) \quad (8)$$

$$B1\text{Provisioning ecosystem services} = w_i \cdot R\text{Provisioning ecosystem services}$$
$$= (0.3556，0.6444) \begin{vmatrix} 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{vmatrix}$$
$$= (1.0000，0.0000，0.0000，0.0000，0.0000) \quad (9)$$

$$B2\text{Regulating ecosystem services} = w_i \cdot R\text{Regulating ecosystem services}$$
$$= (0.3786，0.6214) \begin{vmatrix} 0.3485 & 0.1515 & 0.0000 & 0.0000 & 0.5000 \\ 0.0000 & 0.3411 & 0.1448 & 0.1078 & 0.4063 \end{vmatrix}$$
$$= (0.1319，0.2693，0.0900，0.0670，0.4418) \quad (10)$$

$$B3\text{Culture ecosystem services} = w_i \cdot R\text{Culture ecosystem services}$$
$$= \begin{pmatrix} 0.1616 \\ 0.2335 \\ 0.2549 \\ 0.3500 \end{pmatrix}^T \begin{vmatrix} 0.2838 & 0.5526 & 0.1343 & 0.0262 & 0.0030 \\ 0.3105 & 0.4575 & 0.1612 & 0.0607 & 0.0101 \\ 0.2685 & 0.5260 & 0.1814 & 0.0223 & 0.0018 \\ 0.3314 & 0.5040 & 0.1515 & 0.0131 & 0.0000 \end{vmatrix}$$
$$= (0.3028，0.5066，0.1586，0.0287，0.0033) \quad (11)$$

$$A\text{Ecosystem service assessment of mulberry} - \text{based fishponds} = w_i \cdot R\text{Ecosystem service assessment of mulberry} - \text{base fishponds}$$
$$= (0.5091，0.2338，0.2572) \begin{vmatrix} 0.3028 & 0.5066 & 0.1586 & 0.0287 & 0.0033 \\ 0.1319 & 0.2693 & 0.0900 & 0.0670 & 0.4418 \\ 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{vmatrix}$$
$$= (0.4422，0.3209，0.1018，0.0303，0.1050) \quad (12)$$

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