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An Evaluation Model of Riparian Landscape: A Case in Rural Qingxi Area, Shanghai

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Abstract: The suburbs around Shanghai have a complex river network and a unique Chinese water-town culture. The riparian landscape in the rural Qingxi area has important regional, ecological, and social significance; it serves as an important part of the local bioclimate, but the existing studies on river vegetation did not pay enough attention to the riparian landscape in the countryside around the metropolis. The goal of this study was to examine a comprehensive evaluation model for the river plant landscape in the countryside surrounding a high-density metropolis such as Shanghai in the face of the national policy of rural revitalization and the low-carbon development problem, and to propose optimization strategies accordingly. Therefore, in this study, we selected 91 rivers in the Qingxi area and investigated their plant communities. According to the characteristics of the riparian landscape and its relationship with the river environment and local bioclimate, we classified the 91 riparian landscapes into four types of quadrats: natural landscape, residential recreation, roadside linear landscape, and agricultural landscape. In addition, based on the 13 indicator layers under the categories of ecological carrying capacity, landscape beauty, and social service, we calculated the comprehensive evaluation value (CEV) and comprehensive evaluation index (CEI) of 91 river quadrants using specific formulas to scientifically evaluate the riparian landscape in the rural Qingxi area of Shanghai. Finally, based on the existing problems summarized through data analysis, the researchers proposed five optimization directions: (1) increasing vegetation diversity, (2) choosing native and culturally representative species, (3) improving waterfront planting design, (4) achieving ecological riverbank construction, and (5) building greenway systems and recreational spaces. This study proposed an innovative evaluation model for the riparian vegetation landscape and tested its feasibility by site survey, which provided new visions for future rural landscape research.

Keywords: riparian landscape; an evaluation model; vegetation analysis; rural landscape; Shanghai

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1. Introduction

Studies have shown that the riparian plant community is closely related to the water body and riverbed of the river course. Plant communities are varied in different areas along the riparian zone under different habitat conditions [1]. The plant community in a riparian area is also closely related to the magnitude of water flow and eutrophication [2]. Riparian vegetation not only protects the riverbank from the direct impact of a flood but also maintains biodiversity in the river area [3]. Ecological research has been conducted on urban riparian ecological management, riparian plant species, and riparian plant allocation from the perspective of hydraulic engineering [4]. Research results have highlighted the necessity to focus on local plants, selecting plant species that are suitable to the locality, that are ornamental in various seasons, and that have developed roots and are strongly resistant to erosion [5]. Designers should build a plant-allocation model that is suitable for different locations along the river; the model should address issues such as the reconstruction of different types of revetments, plant communities and biological habitats, the improvement of the urban riparian ecosystem, and the construction of a comfortable riverside landscape with plants chosen for space and contour and four distinct seasons [6].

On the other hand, the riparian zone itself can reduce surface runoff, riparian erosion, and provide absorption buffers for sediments and nutrients flowing into rivers from the land. Abundant, multi-layered river plants can have further benefits, such as providing shade to maintain microclimates and lower temperatures in summer to prevent weed growth, as well as enriching watershed habitats, widening corridors for biological activity, expanding landscape-scale biodiversity, and helping to maintain water quality [7]. Hence, riparian plants can regulate the resilience of rural social ecosystems to cope with possible disturbances caused by social production activities in rural river basins.

As important parts of the surface water-body system, rural rivers and urban rivers are different in terms of ecology, landscape, and social benefits. As Burton et al. [8] indicates, the characteristics of woody river plants vary with the changes in the landscape characteristics of the watershed under the urban–rural gradient, such as biodiversity, biomass turnover, productivity, etc. There are also certain differences in the regulating effects of rural and urban rivers on climate change. Tsai et al. [9] says that both rural and urban channels have cooling effects and warming effects on the surrounding environment of the riverbank. Compared with urban rivers, the variation of riverbank temperature in rural rivers has smaller fluctuations, especially in terms of the warming effect. When the weather is relatively cold, the temperature difference between the riverbank temperature and non-riverbank temperature in an urban area is more obvious. Oleston et al. [10] describes that the increase in sensible heat flux in urban areas, resulting in environmental thermal instability, is one explanation for the difference in warming effects between urban and rural river channels. The difference in the temperature between the two may be one of the reasons why the riparian plants in rural riverbanks are different from those in urban riverbanks. It also explains why differences in land use can lead to the composition of riparian vegetation, from wetland plants to upland plants along the rural–urban gradient change [11].

To evaluate and optimize a rural riparian plant landscape, it is not possible to directly apply the results of research performed on an urban riparian plant landscape. Hence, the research results on the urban river plant landscape cannot be directly applied to evaluate and optimize the rural river plant landscape or its environmental problems. The rural riparian landscape faces more complex challenges than the urban riparian landscape. The deforestation, degradation of river water quality and loss of biodiversity are changing the appearance and ecology of rural river basins [12]. In addition, climate change could cause rural areas to experience higher annual average temperatures and uncertain rainfall in the future, leading to reduced productivity, crops, and the disease of livestock. For rural settlements situated in river areas, the proximity of human social activities to rivers further increases the vulnerability of river ecosystems [13]. According to Folke [14], even slight disturbances can also have unintended social consequences for a fragile socio-ecological system. For a resilient socio-ecological system, disturbance can even turn into opportunity. Thus, the best way to reduce vulnerability is to increase flexibility.

Considering the special geographical, cultural, and economic contexts of rural area in China, as well as the complex challenges faced by the rural riparian plant landscape, which are different from the urban rivers, it is necessary to conduct targeted studies including analysis, evaluation, and optimization of the rural riparian plant landscape. Therefore, this paper aims to establish an evaluation system for the rural river plant landscape including ecological, social and landscape benefits by investigating, analyzing and researching the rural river plant landscape in the Qingxi area of Shanghai. The outcome of this research provides optimized bioclimate planting strategies along the rural riverbank.

2. Research Area and Data

2.1. Research Area

This study selected the Qingxi area (the western region of Qingpu district, Shanghai) of Shanghai as the study site. The Qingxi area of Shanghai is composed of the towns Zhujiajiao, Liantang, and Jinze, with a total area of about 340 km^2. The area has a long history and rich tourism resources. Close to Dianshan Lake, the largest lake in Shanghai, the area has a dense river network and water system, with characteristics typical of Jiangnan Water Town. In recent years, the Shanghai municipal government has attached great importance to river course regulation and riparian plant landscape construction [15]. The construction of a rural riparian plant landscape is of great value to improving the appearance of the village, enhancing environmental governance, building a better local bioclimate, and creating a beautiful village with the traditional style and ecological pastoral scenery of a water town in the area south of the Yangtze River [16]. The Qingxi area has concentrated groups of ancient water towns, which constitute the birthplace of traditional culture in Shanghai. The area has a total of 860 large and small rivers. All 21 natural lakes in Shanghai are located here, with a water surface rate of 32.7%. These lakes and rivers are important water-source-protection areas and ecological protection areas in Shanghai [17].

2.2. Quadrat Selection and Plant Community Investigation

After the analysis of data from 83 administrative villages in the Qingxi area of Shanghai, 10 villages were selected for this study. The selected villages have high population densities and basically perfect transportation facilities, and they are evenly distributed in the region. The central river course with an east–west and north–south orientation was selected from each village. Based on a preliminary investigation of the current situation, quadrats with a rich plant landscape on both sides of the river course were selected. Finally, 75 rural river courses (village-level river courses) and 91 investigation quadrats were proposed as the specific research objects (Table 1).

Table 1. Statistical table of quadrat selection of rural rivers in Qingxi area of Shanghai (source: author.

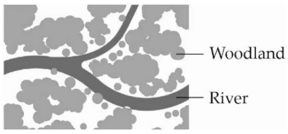
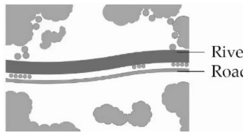
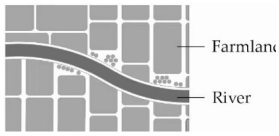
Village Name	Quadrat Quantity	Quadrat Number
Ye Gang	8	01#–08#
Zheng Pu	12	09#–20#
Wang Jin	14	21#–34#
Dong She	10	35#–44#
Shuang Xiang	6	45#–50#
Chen Dong	6	51#–56#
Cen Bu	10	57#–66#
Patriotic	7	67#–73#
Ai Guo	9	74#–82#
Li Zhuang	9	83#–91#

Based on the typical quadrat-recording method of the Farui school and using the obvious boundaries of roads and water edges, a 400 m^2 standard quadrat was established (the quadrat shape is adjusted according to the actual land use). The survey time span was one year and was divided into four seasons. The location of the plant community, habitat conditions, plant species, plant number or area, overall landscape effect of plant configuration, and individual characteristics in the quadrat were recorded in detail, and the plot plan and photos were drawn as an effective supplement to its plane distribution and vertical landscape.

2.3. Types and General Characteristics of Riparian Landscape

According to the characteristics of a riparian landscape and the surrounding environment, the 91 quadrats were preliminarily divided into four landscape categories: natural landscape, residential recreation landscape, roadside linear landscape, and agricultural landscape (Table 2). In terms of the number of quadrat types, most of them are residential recreation landscape (38.5%), agricultural landscape (27.5%) and roadside linear landscape (14.2%), which reflects the fact that the riparian landscape in the Qingxi area is most directly affected by human activities. The natural landscape quadrat with the least amount of human intervention only accounted for 19.8%.

Table 2. Riparian landscape types of rural rivers in the Qingxi area (source: author).

	Riparian Landscape Types	Surrounding Environment and Plant Landscape Characteristics	Schematic Diagram of the Area where the Quadrat is Located	Number/Proportion of Classified Quadrats
1	Natural landscape	The ecological benefits and visual effects of plants in the plots that have not been interfered by human activities for a long time are uneven.		18/19.8%
2	Residential recreation landscape	Located in the rural settlements near the water, the general plant landscape has both ornamental and recreational functions.		35/38.5%
3	Roadside linear landscape	The plant landscape is located between the road near the water and the river, which generally presents a linear landscape corridor.		13/14.2%
4	Agricultural landscape	Riverside plants are staggered with farmland, fish ponds and economic forests, and the plant landscape has the characteristics of field scenery.		25/27.5%

3. Research Method

The rural riparian landscape has ecological, social, and economic significance for the Qingxi area of Shanghai. Qualitative and quantitative data were used to establish a more systematic riparian-landscape-evaluation system to assess the landscape quality level of the 91 quadrats specified above.

3.1. Theoretical Base of Evaluation Model

The existing plant-landscape-evaluation model is mostly based on the AHP method [18–35], since the AHP method can deal with the complex evaluation issues that combine qualitative and quantitative analysis [36]. Through the layer-by-layer decomposition of the evaluation factors of the evaluation object, multiple single criteria are used to evaluate a single factor, and then the single-factor-evaluation results are synthesized. In this way, not only can the overall score of the evaluation object obtained, but the specific characteristics of the evaluation object can also be known according to the single-factor score [27,28]. However, the AHP method also has limitations. First, it relies on the expert's personal decision, which might be subjective. Second, a consistency check needs to be given when comparing layers. If the consistency index requirements are not met, then the AHP evaluation cannot continue [26].

3.1.1. Determining the Evaluation Indicators

This research applied a systematic literature review and the Delphi method via experts to construct the evaluation model. Then, the evaluation indicators were classified and summarized by studying 93 papers related to plant landscape evaluation from Web of Science (WOS). This research identified "Ecological Capacity", "Landscape Aesthetics" and "Social Service" as the three major categories of indicators to evaluate the objective. To further investigate the appropriate indicators, this research first identified and categorized the subcategories under "Ecological Capacity", "Landscape Aesthetics" and "Social Service". Then, the list was sent to experts to judge and generate evaluation indicators for the proposed evaluation model.

3.1.2. Establishment of Index Value and Ranking Standard

In this evaluation, the indicators were divided into quantitative (8) and qualitative (5) types. The quantitative index value was calculated using the Simpson index-calculation formula:

$$D = 1 - \sum_{i=1}^{S} (\mathrm{P}_i)^2 (\text{Between 0 and 1})$$

In the formula, D represents the diversity degree, s is the number of species, and P_i is the probability that a species belongs to category i. Then, the diversity degree is multiplied by the coefficient 10 to obtain the score that corresponds to the index value of a qualitative indicator. Qualitative indicators, which were obtained through a questionnaire survey, are scored on a 5-point scale as excellent, good, medium, poor, and extremely poor, and the scores of 10, 8, 6, 4, and 2 represent each level, respectively [24].

3.1.3. Determining the Weights of Evaluation Indicators

An important feature of the AHP method is to compare the importance of all evaluation indicators in pairs, and then decide the weights of each indicator systematically. This study invited 25 landscape architecture professionals to judge the significance of the indicators through a questionnaire, and adopted the Saaty 9-level scale method (Table 3) to decide the weight of each indicator. Finally, a judgment matrix for the importance of the evaluation indicators of the rural river plant landscape was established.

Table 3. The judgment matrix of evaluation indicators using Saaty 9-level scale method (source: author).

Level	Meaning
1	Comparing indicator *i* and *j*, *i* is as important as *j*
3	Comparing indicator *i* and *j*, *i* is a little more important than *j*
5	Comparing indicator *i* and *j*, *i* is obviously more important than *j*
7	Comparing indicator *i* and *j*, *i* is strongly more important than *j*
9	Comparing indicator *i* and *j*, *i* is extremely more important than *j*
2, 4, 6, 8	Indicates the intermediate value of the above level

Then, using the Yaahp analytic software, the consistency ratio (CR) of the indicator-importance-judgment matrix was calculated and tested to determine the logical consistency of experts' judgment. When CR < 0.1, it means that the consistency of the judgment matrix is acceptable. If CR $\geq$ 0.1, it means that the judgment matrix is inconsistent and needs to be normalized. Finally, the software calculated the weights (Xi) of each evaluation indicator of the rural riparian plant landscape, and then constructed the final evaluation system of the rural riparian plant landscape.

3.2. Establishment of Evaluation Model

The comprehensive evaluation value (CEV) of the riparian landscape is calculated using the following formula:

$$\mathrm{B} = \sum_{i=1}^{n} \mathrm{Fi} * \mathrm{Xi}$$

B represents the CEV of a riparian landscape quadrat, Fi is the score value of a plant landscape quadrat under an evaluation factor, and Xi is the weight value of an affecting indicator. Then, the B value is transformed into the comprehensive evaluation index (CEI), which can be divided into five levels (I to V) to indicate the assessment of a riparian landscape (see Table 4).

Table 4. The CR test of judgment matrix (source: author).

CR Test	A-B	B1-C	B2-C	B3-C
value	0.0279	0.0398	0.0846	0.0699

4. Results and Analysis

4.1. Evaluation of Riparian Landscape

According to the classification and summarization of the evaluation indicators in the 93 related studies, this research generated 10 indicators associated with "Ecological Capacity", 10 indicators associated with "Landscape Aesthetics" and 10 indicators associated with "Social Service", (Figure 1). These 30 indicators were submitted to expert review and were used to generate evaluation indicators for the proposed evaluation model.

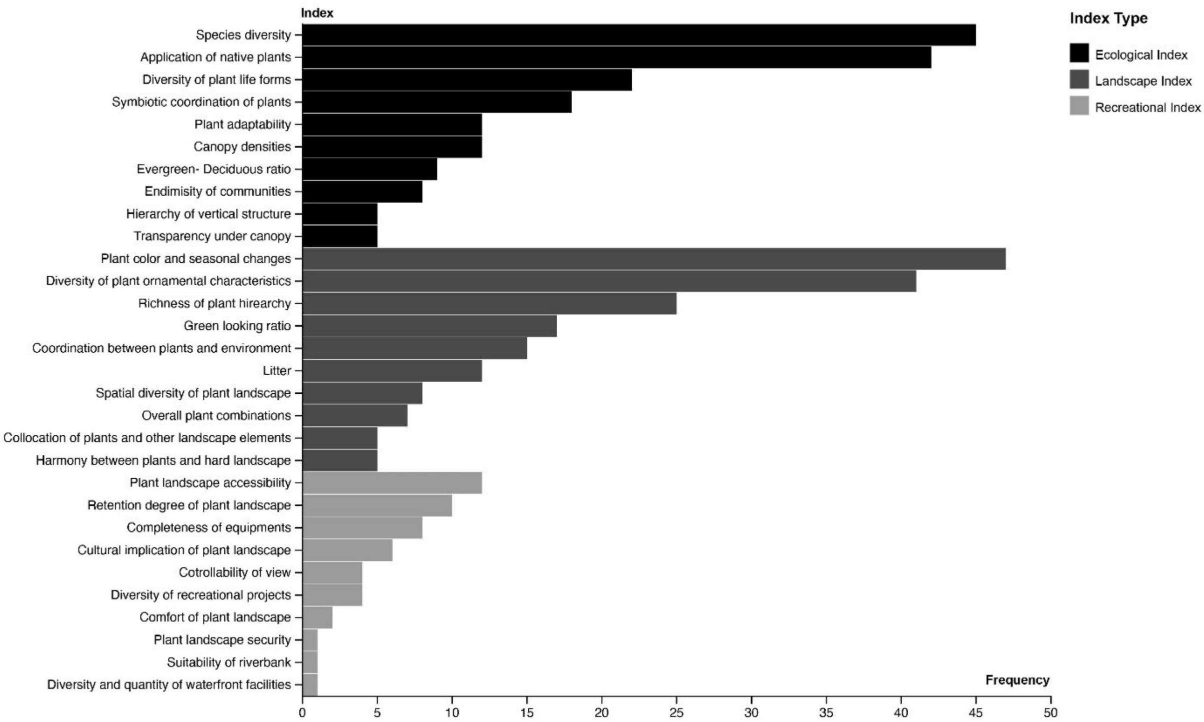


Figure 1. Evaluation indicators of riparian landscape from the literature review (source: author).

Based on the opinions of the experts interviewed and the data obtained from the site study, this study established an evaluation form for the rural river plant landscape which includes 3 criteria (B) and 13 indicators (C) (Table 3). After that, the experts' ratings of the 13 indicators were summarized and used to form a judgment matrix. The consistency analysis was conducted for this pairwise judgment matrix (A-B, B1-C, B2-C, B3-C) and the results indicated that the consistency was acceptable (Table 4). Then, the weights of each indicator were calculated according to the matrix. According to the results of the weight calculation, the most important indicators were C3 (plant adaptability), C5 (spatial diversity of plant landscape), and C6 (plant color and seasonal changes). The indicators with the lowest weights were C12 (plant landscape hydrophilicity) and C10 (plant landscape accessibility). Finally, the evaluation model of the rural river plant landscape was established (Table 5).

Table 5. Proposed evaluation system of a rural riparian landscape in Qingxi area (source: author).

Target Layer A (Weight)	Criterion Layer B (Weight)	Indicator Layer C (Weight)	Weight Ranking	Indicator Property
Evaluation of riparian landscape in rural Qingxi area (1.0)	Ecological capacity B1 (0.4806)	Application of native plants C1(0.0272)	9	Quantitative
		Species diversity C2(0.0988)	4	Quantitative
		Plant adaptability C3(0.2782)	1	Quantitative
		Diversity of plant life forms C4(0.0765)	5	Quantitative
	Landscape aesthetics B2 (0.4054)	Spatial diversity of plant landscape C5(0.1692)	2	Quantitative
		Plant color and seasonal changes C6(0.109)	3	Quantitative
		Diversity of plant ornamental characteristics C7(0.0702)	6	Quantitative
		Coordination between plants and environment C8(0.0328)	8	Qualitative
		Harmony between plants and hard landscape C9(0.0241)	11	Qualitative
	Social service B3 (0.1140)	Plant landscape accessibility C10(0.0189)	12	Qualitative
		Retention degree of plant landscape C11(0.0244)	10	Quantitative
		Plant landscape hydrophilicity C12(0.0073)	13	Qualitative
		Plant landscape security C13(0.0633)	7	Qualitative

4.2. Evaluation Results

Through the field investigation and survey, the research team collected vegetation data for all the selected quadrats of rivers in the rural Qingxi area. Based on the formulas above, the data were processed using RStudio statistics software, and the CEI of 91 quadrats of rivers were calculated (Table 6).

Table 6. Evaluation results of riparian landscape in rural Qingxi area (source: author).

Quadrat	Ecological Capacity	Landscape Aesthetics	Social Service	CEI (%)	CEI Level
01#	3.73	1.98	0.49	62.23	III
02#	3.68	1.84	0.84	63.74	III
03#	2.71	2.28	0.58	55.86	III
04#	2.99	2.05	0.51	55.62	III
05#	2.29	2.04	0.45	47.98	IV
06#	2.96	1.95	0.45	53.79	IV
07#	3.27	2.41	0.53	62.26	III
08#	2.33	1.72	0.32	43.83	IV
09#	3.38	2.06	0.53	59.92	III
10#	3.22	2.51	0.63	63.77	III
11#	3.13	1.7	0.64	54.90	IV
12#	3.05	2.22	0.59	58.79	III
13#	3.08	2.37	0.77	62.35	III
14#	2.75	1.55	0.81	51.34	IV
15#	2.14	2.42	0.61	51.80	IV
16#	3.35	2.11	0.63	61.03	III
17#	3.1	1.77	0.58	54.60	IV
18#	2.47	2.09	0.28	48.54	IV
19#	2.83	2.07	0.7	56.13	III
20#	2.44	2.07	0.62	51.45	IV
21#	2.32	2.22	0.65	52.02	IV

Table 6. *Cont.*

Quadrat	Ecological Capacity	Landscape Aesthetics	Social Service	CEI (%)	CEI Level
22#	2.87	1.89	0.48	52.49	IV
23#	3.09	1.85	0.48	54.42	IV
24#	2.21	1.26	0.6	40.84	IV
25#	3.32	2.56	0.59	64.89	III
26#	2.78	1.71	0.71	52.18	IV
27#	2.39	2.02	0.6	50.25	IV
28#	2.73	1.27	0.79	48.10	IV
29#	2.84	1.77	0.59	52.12	IV
30#	2.8	2.41	0.42	56.46	III
31#	2.92	1.9	0.49	53.24	IV
32#	1.91	0.71	0.47	31.10	V
33#	2.71	1.96	0.39	50.71	IV
34#	3.61	2.36	0.86	68.46	III
35#	3.82	2.48	0.57	68.77	III
36#	2.81	2.5	0.66	59.78	III
37#	2.79	1.48	0.57	48.60	IV
38#	2.84	1.28	0.61	47.47	IV
39#	3.37	2.18	0.65	62.15	III
40#	3.19	2.37	0.66	62.31	III
41#	2.08	0.99	0.35	34.29	V
42#	1.67	2.28	0.3	42.62	IV
43#	1.89	1.26	0.57	37.41	V
44#	2.28	2.5	0.66	54.47	IV
45#	1.74	2.25	0.4	43.97	IV
46#	1.82	2.16	0.62	46.19	IV
47#	2.24	0.64	0.44	33.40	V
48#	2.5	2.25	0.47	52.27	IV
49#	3.27	2.04	0.39	57.16	III
50#	2.85	2.33	0.7	58.98	III
51#	2.48	2.08	0.49	50.70	IV
52#	2.82	2.3	0.38	55.17	III
53#	2.57	2.54	0.5	56.23	III
54#	3.63	2.33	0.58	65.54	III
55#	2.69	1.93	0.62	52.63	IV
56#	3.12	2.15	0.62	59.01	III
57#	3.97	2.66	0.65	72.89	II
58#	3.06	1.71	0.67	54.56	IV
59#	3.04	2.07	0.81	59.41	III
60#	3.49	2.09	0.9	64.93	III
61#	2.97	1.47	0.56	50.17	IV
62#	2.52	2.05	0.66	52.47	IV
63#	2.58	1.7	0.51	47.95	IV
64#	3.01	1.94	0.55	55.11	III
65#	3.82	2.26	0.81	69.00	III
66#	2.42	2.16	0.67	52.64	IV
67#	3.02	2.08	0.63	57.50	III
68#	2.73	2.4	0.71	58.64	III
69#	2.8	1.94	0.72	54.73	IV
70#	3.2	1.93	0.39	55.38	III
71#	3.14	1.5	0.46	51.12	IV
72#	2.94	2.06	0.51	55.27	III
73#	2.45	2.14	0.74	53.43	IV
74#	3.52	2.23	0.46	62.14	III
75#	2.99	1.98	0.55	55.38	III
76#	3.69	2.08	0.6	63.91	III
77#	2.78	1.42	0.47	46.86	IV
78#	3.15	2.36	0.61	61.40	III
79#	3.81	2.26	0.44	65.22	III

Table 6. *Cont.*

Quadrat	Ecological Capacity	Landscape Aesthetics	Social Service	CEI (%)	CEI Level
80#	3.15	2.08	0.55	57.88	III
81#	3.02	2.36	0.5	58.92	III
82#	3.41	0.44	0.76	46.21	IV
83#	3.28	1.33	0.72	53.51	IV
84#	3.27	1.96	0.82	60.64	III
85#	2.89	1.85	0.68	54.27	IV
86#	2.38	1.81	0.58	47.85	IV
87#	2.35	2.05	0.7	51.14	IV
88#	3.14	2.46	0.57	61.80	III
89#	3.36	2.58	0.62	65.63	III
90#	2.79	0.86	0.49	41.52	IV
91#	2.81	1.87	0.54	52.40	IV

4.3. Analysis

4.3.1. Overall Evaluation

First, based on the CEI level (Table 7), 94.50% of the rural river plant landscape in the Qingxi area of Shanghai was considered average (level III) or poor (level IV). Forty-two quadrats (46.15%) in this survey were evaluated as average, and 44 quadrats (48.35%) as poor. None (0) of the quadrats were found to have an excellent landscape effect (level I), one (1.10%) had a good landscape effect (level II), and the other four (4.40%) had poor landscape effects (level V).

Table 7. Statistical table of plant landscape classification CEI level (source: author).

Quadrat	CEIAverage Value(%)	CEI Grade / Grade Definition	I (85–100%) Excellent	II (70–85%) Good	III (55–70%) Medium	IV (40–55%) Poor	V (<40%) Very Poor	Total
All quadrats	54.60	Number of samples (PCs)	0	1	42	44	4	91
		Proportion (%)	0	1.10	46.15	48.35	4.40	100
Natural landscape	59.11	Number of samples (PCs)	0	0	13	5	0	18
		Proportion (%)	0	0	72.22	27.78	0	100
Agricultural landscape	52.73	Number of samples (PCs)	0	0	17	8	0	25
		Proportion (%)	0	0	68.00	32.00	0	100
Roadside linear landscape	57.78	Number of samples (PCs)	0	0	8	5	0	13
		Proportion (%)	0	0	61.54	38.46	0	100
Residential recreation landscape	52.42	Number of samples (PCs)	0	1	13	17	4	35
		Proportion (%)	0	2.86	37.14	48.57	11.43	100

Second, the overall landscape effect of the natural landscape quadrat was the best; the average value of its CEI was 59.11%, of which the landscape of level III and above accounted for 72.22%. The average value of the roadside linear landscape CEI was higher than that of the agricultural landscape type, but the proportion of the landscape rated level III and higher was lower than that of the agricultural landscape type. The average CEI level of the residential recreation landscape was the lowest (52.42%), and there were great differences among the evaluations of individual quadrats. All the level II landscapes (2.86%) and level V landscapes (11.43%) were in residential recreation quadrats. This was also seen in the significant-difference analysis of the evaluation data of the four types of quadrats. The *p*-value of the data from the residential recreation quadrats was much lower than that of the other three groups of data, with great differences between them.

4.3.2. Vegetation Characteristics Analysis

For the quadrats with comprehensive evaluation level III and above, the vegetation type was mainly a mix of evergreen and deciduous or of coniferous and broad-leaved (65.12%); the plant formation was mainly a combination of Metasequoia and Cinnamomum camphora or of weeping willow and Cinnamomum camphora (53.49%); and the single-layer structure type of plant configuration accounted for only 9.3%. The results showed that the main plant types of the rural river quadrats in the Qingxi area of Shanghai were homogenous, with low diversity and species richness. Camphor (58.24%) was planted in 53 quadrats. Metasequoia dominated 33 quadrats (36.26%), 24 (26.37%) were dominated by camphor, and 18 (19.78%) were dominated by weeping willow. Only 16 (17.58%) had combinations of other types, such as beech, purple leaf plum, Broussonetia papyrifera, and Magnolia grandiflora. The majority of genera and species came from the families Gramineae, Rosaceae, Compositae, Magnoliaceae, and Oleaceae, accounting for 45% of the total plant species investigated. Other representative plant genera and species in Shanghai are less used.

Finally, the analysis of the 13 indicator layers and the average CEI levels of the four types of landscape showed the highest scores for C8 (coordination between plants and surrounding environment) and C3 (plant adaptability) and, in general, the lowest scores for C7 (diversity of plant ornamental characteristics) and C5 (spatial diversity of plants). The natural landscape had obvious advantages over the other three types in terms of the three ecological benefit indicators of C1, C2, and C3, and its scores for other indicators were also better than the overall average value. The roadside linear landscape was relatively good in C6 (color and seasonal change) and C13 (safety) but was defective in C12 (hydrophilicity). The overall evaluation value of agricultural landscape was low, and its scores for C1, C2, C10, and C13 were far lower than those of other types of landscape (Figure 2).

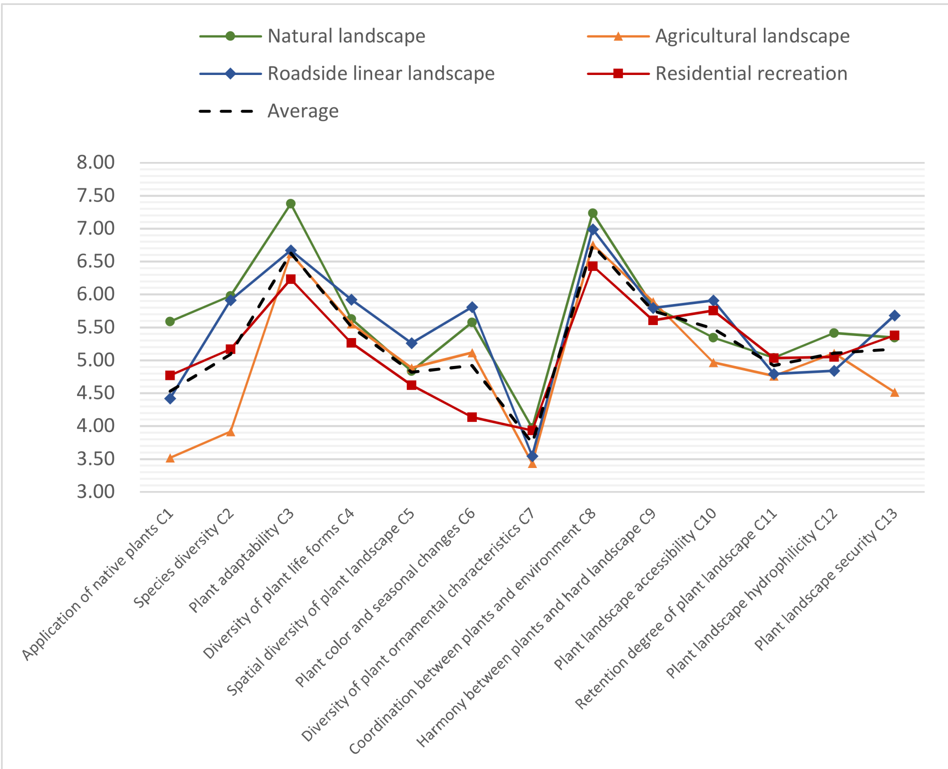


Figure 2. Landscape type and indicator layer analysis (source: author).

4.4. Suggestions on Improving the Rural River Landscape in Qingxi Area

The comprehensive evaluation results of the value of the rural riparian landscape in Qingxi area of Shanghai were low; especially at the eastern edge, the riparian landscape urgently needs to be sorted out and optimized. Based on this study, researchers proposed five primary optimization strategies for the riparian landscape in the rural Qingxi area of Shanghai (Table 8): (1) increasing vegetation diversity, (2) choosing native and culturally representative species, (3) improving waterfront planting design, (4) achieving ecological riverbank construction, and (5) building a greenway system and recreational space.

Table 8. Summary of optimization strategies (source: author).

Strategies	Method	Goal
Increasing Vegetation Diversity	Using more species in a reasonable way; create more effective plant communities.	Enhance ecological resilience; increase biodiversity; improve ornamental characteristics.
Choosing Native and Culturally Representative Species	Increase the proportion of native plants.	Improve natural and cultural. Improve geographical identifiability; making plants and communities more adaptable to the local environment.
Achieving Ecological Riverbank Construction	Utilizing bioengineering approaches; using a more naturalized shape.	Reduce surface runoff and protect water bodies; provide more diverse habitats for animals, plants, microorganisms, etc.
Improving Waterfront Planting Design	Make full use of the gentle slope of a riverside; protect existing wetland; create more space for vegetations.	Improve the diversity of waterfront plant communities; purify water bodies; restore ecological environment
Building a Greenway System and Recreational Space	Connect riverside trails with the greenway system; recreational spaces; low-impact development.	Enhance rural attractiveness; create economic, social and environment benefits.

4.4.1. Increasing Vegetation Diversity

The three lowest average scores among the 13 indicators layers were (C7) diversity of plant ornamental characteristics, (C5) plant spatial diversity and (C2) species diversity. Rural channels and their banks are considered ecologically intersecting zones and should have more complex biodiversity than single patches. Increasing the diversity of riparian plants in rural rivers can help improve habitat types, provide more habitats for birds and amphibians, and help reduce pests and diseases [37]. It also contributes to restoring more ecosystem functions that enhance the ecological resilience of rural riparian environments. In addition, compared with single planting, the use of diversified planting can easily make the river landscape more ornamental and improve its ornamental value, recreational value and social benefit. Therefore, to optimize the riparian landscape in the rural Qingxi area, it is necessary to enhance the diversity and richness of plant communities. The diversity of planting plane combinations enriches and improves the vertical planting structure to enhance the self-regulating ability of the rural river plant ecosystem.

4.4.2. Choosing Native and Culturally Representative Species

As shown in the previous analysis, the application of native plants (C1) is one of the indicators receiving the least attention. Most people have a higher preference for neat and horticultural plant landscapes and think native plant landscapes are chaotic and lack ornamental value. People often fail to notice the importance of ecology [38]. Recently, ecological concepts have gradually entered the public eye and people have begun to prefer landscapes composed of native plants. [39,40].

First, the selection of native tree species can better represent the natural and cultural characteristics of the region, making the rural landscape more regional. In addition, native plants are often more adaptable to the local environment [41], which is conducive to the restoration of ecosystem functions, promotes carbon sequestration, reduces pollution, and contributes to local sustainable development [42]. The vegetation landscape of the rural rivers in the Qingxi area of Shanghai should reflect the characteristics of a water town. The landscape design should use native plants and meet the needs of a waterfront ecological environment (Table 9).

Table 9. Recommended native plant list (source: author).

	Ecological Restoration Plant	Landscape Aesthetics Plants	Ecological and Economical Friendly Plants
Evergreen Canopy	*Cinnamomum septentrionale, Eriobotrya japonica, Ligustrum lucidum, Pinus elliottii, Castanopsis sclerophylla, Quercus glauca, Osmanthus fragrans, Phyllostachys heteroclada, Cyperus alternifolius, Phyllostachys sulphurea var. viridis, Bambusa textilis*	*Cinnamomum septentrionale, Ligustrum lucidum, Osmanthus fragrans, Trachycarpus fortunei, Ilex rubra*	*Phyllostachys violascens, Phyllostachys violascens cv. Prevernalis, Phyllostachys edulis, Eriobotrya japonica, Citrus medica, Citrus maxima*
Deciduous Canopy	*Salix babylonica, Salix rosthornii, Taxodium distichum, Metasequoia glyptostroboides, ×Taxodiomera peizhongii, Taxodium distichum var. imbricatum, Pterocarya stenoptera, Ficus carica, Poncirus trifoliata, Celtis sinensis, Zelkova serrata, Ailanthus altissima, Toona sinensis, Melia azedarach, Triadica sebifera, Firmiana simplex, Diospyros kaki, Paulownia fortunei, Euonymus maackii, Acer palmatum, Camptotheca acuminata*	*Celtis sinensis, Zelkova serrata, Acer buergerianum, Albizia julibrissin, Triadica sebifera, Metasequoia glyptostroboides, Taxodium distichum var. imbricatum, Taxodium distichum, ×Taxodiomera peizhongii, Rhus chinensis, Euonymus maackii, Staphylea forrestii, Melia azedarach*	*Morus alba, Maclura tricuspidata, Prunus persica, Toona sinensis, Triadica sebifera, Vernicia fordii, Rhus chinensis, Toxicodendron succedaneum, Toxicodendron vernicifluum, Diospyros kaki, Paulownia fortunei*
Evergreen Shrub	*Ficus pumila, Senna spectabilis, Mucuna sempervirens, Citrus maxima, Citrus reticulata, Euonymus fortunei, Ilex cornuta, Ilex chinensis, Nerium oleander, Trachelospermum jasminoides, Adina pilulifera, Gardenia jasminoides, Bambusa multiplex, Indocalamus tessellatus*	*Nerium oleander, Adina pilulifera, Ligustrum sinense var. variegatum, Camellia sasanqua*	*Camellia oleifera, Poncirus trifoliata, Citrus reticulata*
Deciduous Shrub	*Chimonanthus praecox, Cercis chinensis, Amorpha fruticosa, Wisteria sinensis, Buddleja lindleyana, Hibiscus mutabilis, Celastrus orbiculatus, Tamarix chinensis, Hibiscus syriacus, Lagerstroemia indica, Rhododendron simsii, Forsythia suspensa, Vitex negundo var. cannabifolia, Adina rubella, Boehmeria nivea, Akebia trifoliata, Lespedeza thunbergii subsp. formosa*	*Chimonanthus praecox, Rosa multiflora, Hibiscus mutabilis, Malus halliana, Hibiscus hamabo, Lagerstroemia indica, Cercis chinensis, Wisteria sinensis, Rhododendron simsii, Forsythia viridissima, Vitex negundo var. cannabifolia, Hibiscus syriacus, Viburnum macrocephalum, Sambucus williamsii, Weigela florida*	*Pyrus spp, Ficus carica, Prunus salicina*
Herb	*Adiantum capillus-veneris, Aristolochia debilis, Persicaria orientalis, Phedimus aizoon, Toxicodendron radicans subsp. hispidum, Trifolium pratense, Trifolium repens, Malva cathayensis, Dichondra micrantha, Colocasia esculenta, Hemerocallis fulva, Ophiopogon bodinieri, Lycoris radiata, Iris lactea, Imperata cylindrica, Arundo donax, Miscanthus sinensis cv. Gracillimus, Pennisetum alopecuroides, Saccharum arundinaceum, Chrysopogon zizanioides, Zoysia japonica, Sedum sarmentosum, Eremochloa ophiuroides, Lolium perenne*	*Houttuynia cordata, Dichondra micrantha, Scutellaria barbata, Cirsium japonicum, Eremochloa ophiuroides, Hosta plantaginea, Hosta ventricosa, Cortaderia selloana cv. Pumila, Pennisetum alopecuroides, Miscanthus sinensis cv. Gracillimus, Zoysia japonica, Hemerocallis fulva, Ophiopogon bodinieri, Canna indica, Lycoris radiata, Saccharum arundinaceum, Iris tectorum*	*Hemerocallis fulva, Ophiopogon japonicus, Colocasia esculenta*

Table 9. *Cont.*

	Ecological Restoration Plant	Landscape Aesthetics Plants	Ecological and Economical Friendly Plants
Aquatic	*Oenanthe javanica, Sagittaria trifolia subsp. leucopetala, Euryale ferox, Lythrum salicaria, Nymphoides peltata, Typha orientalis, Phragmites australis, Zizania latifolia, Schoenoplectus triqueter, Brasenia schreberi, Alisma plantago-aquatica, Arundo donax, Coix lacryma-jobi, Acorus calamus, Juncus setchuensis, Iris pseudacorus, Typha angustifolia, Canna indica, Ipomoea aquatica, Nelumbo nucifera, Thalia dealbata, Pontederia cordata, Schoenoplectus tabernaemontani, Juncus effusus, Myriophyllum verticillatum, Nymphoides lungtanensis, Nymphaea tetragona, Potamogeton wrightii, Ceratophyllum demersum, Hydrilla verticillata, Potamogeton crispus, Vallisneria natans*	*Thalia dealbata, Nelumbo nucifera, Nymphaea tetragona, Ceratophyllum demersum, Alopecurus pratensis, Arundo donax, Coix lacryma-jobi, Phragmites australis, Acorus calamus, Juncus effusus, Typha orientalis, Iris pseudacorus, Pontederia cordata, Lythrum salicaria*	*Sagittaria trifolia subsp. leucopetala, Trapa bispinosa, Nelumbo nucifera, Oenanthe javanica, Brasenia schreberi, Euryale ferox, Coix lacryma-jobi, Zizania latifolia*

4.4.3. Improving Waterfront Planting Design

Natural floodplains are one of the most biodiverse habitat types, and they provide decent ecosystem services as well as social and economic benefits to humans [43]. The waterfront planting design should first make full use of the gentle slope of a riverside ecology to build a natural wetland and a healthy ecosystem. By imitating the natural ecological wetland design, it not only provides corridors for wildlife migration and habitation, but also provides viewing and leisure places for humans. The design of the waterfront plant community should be based on the characteristics of the river channel, hydrology and water quality, surrounding environment, etc. [44] in order to construct different compositions of submerged plants, floating-leaf plants and emergent plants. They should be adapted from the river bottom → normal water level → flood level → flood level. The above sloping land → riparian green belt water and land gradient change along the river plant community (Table 10) in order to improve the stability and diversity of the water ecosystem.

4.4.4. Achieving Ecological Riverbank Construction

The riverbank is a relatively vital part of both rural and urban rivers. In order to prevent the riverbank from being eroded, most of the countermeasures are from the perspective of civil engineering, including building artificial revetments and turning riverbank corridors into revetments with a single texture and shape [45]. The loss of riparian plants leaves no room for microorganisms, amphibians and fish to thrive. This reduces the biodiversity of the riparian environment. Retaining natural tidal flats is a more sustainable method than artificial riverbanks. Considering the construction and design of a riverbank, an ecological riverbank landscape that has a flexible form should be created to provide a sustainable environment for aquatic plants and animals. At the same time, designers should explore various forms of permeable pavement and low-impact riverbank structures. Especially for natural and inhabited rivers, excessive artificial construction should be prevented. Some artificial structures that affect the natural environment should be removed and ecology-friendly landscape design with natural plants community should be created instead. Vertical greening and floating wetland beds are also good methods to soften the riverbank and increase the planting area of aquatic plants. It is also necessary to control the water pollution caused by rainfall and municipal wastewater. Herbs and shrubs with high coverage, developed roots, and strong stress resistance should be selected for riverbank planting.

Table 10. Recommended plant combination list (source: author).

Planting Combination	Aquatic Plants (Below the Normal Water Level)	Normal Water Level to Flood Level	Above Flood Level	River Riparian	Applicable Riparian Landscape Type
Type 1	**Emerged Plants** *Typha orientalis*	**Canopy** *Metasequoia glyptostroboides* **Shrub** *Indigofera bungeana* **Herb** *Lythrum salicaria*	**Canopy** *Cinnamomum camphora* **Shrub** *Hibiscus mutabilis* **Herb** *Eremochloa ophiuroides*	**Canopy** *Cinnamomum camphora, Triadica sebifera* **Shrub** *Weigela florida* **Herb** *Eremochloa ophiuroides*	Residential recreation, roadside linear landscape, agricultural landscape
Type 2	**Emerged Plants** *Cortaderia selloana*	**Canopy** *Salix rosthornii* **Shrub** *Lespedeza thunbergii subsp. Formosa* **Herb** *Persicaria orientalis*	**Canopy** *Ligustrum lucidum* **Shrub** *Amorpha fruticose* **Herb** *Cynodon dactylon*	**Canopy** *Melia azedarach* **Shrub** *Photinia serratifolia* **Herb** *Cynodon dactylon*	Natural landscape, agricultural landscape
Type 3	**Swimming Plants** *Euryale ferox*	**Canopy** *Pinus elliottii* **Shrub** *Hibiscus mutabilis* **Herb** *Canna indica*	**Canopy** *Pterocarya stenoptera* **Shrub** *Hibiscus mutabilis* **Herb** *Zoysia japonica*	**Canopy** *Ligustrum lucidum* **Shrub** *Cercis chinensis* **Herb** *Zoysia japonica*	Natural landscape, agricultural landscape
Type 4	**Emerged Plants** *Phragmites australis*	**Canopy** *Celtis sinensis* **Shrub** *Hibiscus mutabilis* **Herb** *Saccharum arundinaceum*	**Canopy** *Trachycarpus fortune* **Shrub** *Bambusa multiplex* **Herb** *Jasminum mesnyi*	**Canopy** *Salix babylonica* **Shrub** *Indocalamus tessellatus* **Herb** *Pennisetum alopecuroides*	Natural landscape, agricultural landscape
Type 5	**Emerged Plants** *Typha angustifolia*	**Canopy** *Taxodium distichum* **Shrub** *Nerium oleander* **Herb** *Arundo donax cv. Versicolor*	**Canopy** *Koelreuteria bipinnata cv. Integrifoliola* **Shrub** *Nerium oleander* **Herb** *Canna indica*	**Canopy** *Cinnamomum septentrionale* **Herb** *Cynodon dactylon*	Roadside linear landscape
Type 6	**Hydrophyte Herb** *Taxodium distichum var. imbricatum*	**Canopy** *Triadica sebifera* **Shrub** *Cercis chinensis* **Herb** *Lythrum salicaria*	**Canopy** *Liquidambar formosana* **Shrub** *Lagerstroemia indica* **Herb** *Ophiopogon japonicus*	**Canopy** *Liquidambar formosana* **Shrub** *Osmanthus fragrans* **Herb** *Cynodon dactylon*	Natural landscape, agricultural landscape

Table 10. *Cont.*

Planting Combination	Aquatic Plants (Below the Normal Water Level)	Normal Water Level to Flood Level	Above Flood Level	River Riparian	Applicable Riparian Landscape Type
Type 7	**Emerged Plants & Hydrophyte Herb** *Schoenoplectus tabernaemontani, Nelumbo nucifera*	**Canopy** *Celtis julianae* **Shrub** *Salix integra cv. Hakuro Nishiki* **Herb** *Pontederia cordata*	**Canopy** *Liquidambar formosana* **Shrub** *Gardenia jasminoides* **Herb** *Medicago sativa*	**Canopy** *Cornus kousa subsp. Chinensis* **Shrub** *Hypericum monogynum* **Herb** *Medicago sativa*	Residential recreation
Type 8	**Hydrophyte Herb** *Iris pseudacorus*	**Canopy** *Salix babylonica* **Shrub** *Canna indica* **Herb** *Canna indica*	**Canopy** *Ligustrum lucidum* **Shrub** *Hibiscus syriacus, Malus halliana* **Herb** *Hemerocallis fulva*	**Canopy** *Ligustrum lucidum, Acer palmatum cv. Atropurpureum* **Shrub** *Hibiscus syriacus, Osmanthus fragrans* **Herb** *Hemerocallis fulva*	Residential recreation
Type 9	**Emerged Plants** *Sagittaria trifolia subsp. Leucopetala, Nymphaea tetragona*	**Canopy** *Pterocarya stenoptera* **Shrub** *Hibiscus mutabilis* **Herb** *Lythrum salicaria*	**Canopy** *Melia azedarach* **Shrub** *Hibiscus hamabo* **Herb** *Miscanthus sinensis cv. Gracillimus*	**Canopy** *Eriobotrya japonica* **Shrub** *Weigela florida* **Herb** *Cynodon dactylon*	Residential recreation
Type 10	**Emerged Plants** *Acorus calamus, Typha angustifoli, Cyperus alternifolius*	**Canopy** $\times$ *Taxodiomera peizhongii* **Shrub** *Nerium oleander* **Herb** *Iris pseudacorus*	**Canopy** *Koelreuteria bipinnata cv. Integrifoliola* **Shrub** *Bambusa multiplex* **Herb** *Hemerocallis fulva*	**Canopy** *Sapindus Saponaria* **Shrub** *Lagerstroemia indica* **Herb** *Ophiopogon japonicus*	Roadside linear landscape

4.4.5. Building a Greenway System and Recreational Space

Rural sustainable development is a multi-dimensional concept involving three dimensions of the rural environment, economy and society [46]. Another consideration is the activity requirements of local people and tourists. A greenway system and related recreational landscape space should be proposed based on the improved riparian landscape. Riverside trails should be connected with the greenway, agriculture and wildlife habitats. It should provide the rural population with the same cultural, entertainment and healthcare benefits as the urban residents. The necessary recreational spaces, such as plazas, open waterfront space, playgrounds, and sports courts, should be designed along this greenway system for convenient access by the main villages and communities [47]. The design also sets recreational spaces of different capacities and types according to the characteristics of the surrounding environment and the density of the resident population. The capacity of recreational space on both sides of the inhabited recreational river is much higher than that of the natural landscape river far away from the village. The pastoral landscape river plants should enrich the farmland landscape with richer colors and diverse ornamental plants, and become a rest place for farmers.

5. Discussion and Conclusions

Through the literature comparison, the result indicates that several main indicators of the evaluation index system of waterfront plant landscape in different regions are relatively similar, while the weights of the evaluation indicators are mostly different [18–35], which represents the fact that people's expectations for plant landscapes in different regions are different. Rural areas are the ecological base of metropolitan areas, and most research societies attach great importance to their landscape ecological service functions. However, the results of this study found that the weights of ecological capacity and landscape aesthetics in the evaluation system of rural river landscapes in the Qingxi area of Shanghai were basically the same. This indicates that the aesthetic value of river landscapes in metropolitan and rural areas was considered as important as ecological value. In other words, given that the ecological environment of rural areas has advantages compared with urban areas, the beauty of the landscape will now be more important. This study found that the overall evaluation of the rural river plant landscape in the Qingxi area of Shanghai was relatively low, especially in the eastern border area. The eastern part of the Qingxi area is closer to the Shanghai metropolis, and its population density and construction density are higher than other areas. It is a hub area for the connection and interaction between the Qingxi area and Shanghai. These results agree with the results of the existing research [11,12,14], i.e., that the social and economic activities of human beings are the essential factors that have the greatest impact on the rural riparian landscape environment. Therefore, the more human-concentrated areas there are, the more human ecological interventions that are needed, such as plant community optimization, carbon-neutral design, and low-impact development; these strategies ensure the resilience of the waterfront environment. However, the plant space adjacent to the river channel in Qingxi has low diversity in terms of species, structure, space, season and ornamental characteristics, especially near the high-density residential and recreational river channel. The results fully show that the current level of the rural riparian landscape and construction in the Qingxi area needs to be urgently optimized in terms of its design and governance.

From the perspective of bioclimate, the surrounding ecological environment composed of river vegetation has a higher environmental cooling effect than urban rivers, which can effectively adjust the surrounding microclimate, as well as radiate a wider area to assist in adjusting the urban climate. Abundant river plants can provide shade to maintain microclimates, maintain lower temperatures in summer to prevent weed growth, enrich watershed habitats, provide wider corridors for biological activities, and expand landscape-scale biodiversity. It can be seen that the riparian landscape in the Qingxi region could control the resilience of the rural social ecosystem and play a subtle role in the climate regulation of the Shanghai metropolis. Therefore, this study proposes a landscape-optimization strategy for the riparian landscape in the Qingxi region from five perspectives: (1) increasing vegetation diversity, (2) choosing native and culturally representative species, (3) improving waterfront planting design, (4) achieving ecological riverbank construction, and (5) building greenway systems and recreational spaces. The significance of this research is to improve the ecological resilience of the riparian landscape in the Qingxi region, thereby protecting the native biodiversity of Qingxi, improving the rural living environment around Shanghai, and optimizing the local bioclimate and adjusting the broader climate of the Shanghai metropolis.

The rural areas around the metropolis have high population density and complex land use. Therefore, according to the characteristics of rural land use, this study divides the waterfront plant environment in Qingxi into four categories: natural landscape, agricultural landscape, roadside linear landscape and residential recreation landscape. The evaluation results found that the evaluation index scores of the four types of waterfront plant landscapes are very consistent (Figure 1). The average score of ecological indicators of natural landscape type is lower than that of rural recreational waterfront environment, and the average score of social indicators of waterfront plant landscape in rural recreational areas does not show that it satisfies people's higher recreational activity needs. On the one hand, this result reflects that the problems existing in the current situation of the river landscape in the Qingxi area are very consistent, which can clarify the specific direction for the overall optimization of the river landscape in the Qingxi area. Evaluating different types of land uses blurs the distinction between different types of landscapes. The follow-up research will continue to deepen on the basis of this research. For each type of river plant landscape, especially for the residential recreation landscape with a very large difference in evaluation scores, a more targeted evaluation system will be established to propose more detailed policies in order to make further recommendations.

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