sustainability

MDPI

Article

Spatial and Temporal Distribution of Riparian Vegetation and Its Influencing Factors in the Hilly Areas of Zhejiang Province, China

Huizhen Zhang [1], Liting Sheng [2,*], Jihong Xia [1], Shunan Dong [1], Jiaxin Xu [1], Feiyang Sun [1] and Yuanshuo Lu [1]

[1] College of Agricultural Science and Engineering, Hohai University, Nanjing 210098, China; 231310020005@hhu.edu.cn (H.Z.); syjhxia@hhu.edu.cn (J.X.); dsn@hhu.edu.cn (S.D.); xujiaxin041@163.com (J.X.); ab2388847901@163.com (F.S.); hushhh_7@163.com (Y.L.)

[2] State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China

* Correspondence: litingsheng@hhu.edu.cn

Abstract

Restoring vegetation in riparian zones is regarded as a best management practice in river restoration. Vegetation characteristics and diversity play a decisive role in maintaining ecological function in riparian zones. This study focuses on multi-scale distribution of herbaceous vegetation composition and diversity in riparian zones of three small–medium rivers in northern Zhejiang Province, China, through two years' field investigations. Meanwhile, the main environmental and hydrological factors were analyzed by principal component analysis (PCA). The results indicated the following: (1) A total of 220 herbaceous plant species belonging to 55 families and 162 genera were recorded, with Poaceae (39 species, 17.73%) and Asteraceae (32 species, 14.55%) being the most abundant families. (2) Significant differences in riparian vegetation biomass and diversity were observed at both the river basin and river segment scales, in which upstream areas always showed higher richness and greater diversity of riparian vegetation. (3) The primary environmental factors influencing vegetation distribution varied with spatial scale: At the river scale, soil organic matter and water nitrogen were key factors affecting vegetation diversity, while riparian vegetation diversity was also influenced by water area. At the river segment scale, aquatic environmental factors exerted a more pronounced effect on vegetation diversity, with total phosphorus and nitrate nitrogen in water being the primary influencing factors. This research provides a theoretical basis for the restoration and sustainable management of riparian ecosystems in the study area and other similar regions.

Keywords: vegetation diversity and composition; multiscale distribution; soil and water environment factors; riparian zone

check for updates

Academic Editors: Huafeng Wang and Giulia Caneva

Received: 7 August 2025
Revised: 6 September 2025
Accepted: 23 September 2025
Published: 25 September 2025

Citation: Zhang, H.; Sheng, L.; Xia, J.; Dong, S.; Xu, J.; Sun, F.; Lu, Y. Spatial and Temporal Distribution of Riparian Vegetation and Its Influencing Factors in the Hilly Areas of Zhejiang Province, China. *Sustainability* **2025**, *17*, 8609. https://doi.org/10.3390/su17198609

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Riparian zones, as critical transitional areas between terrestrial and aquatic ecosystems, exhibit unique ecological gradient characteristics and dynamic edge effects [1–3]. These regions are vital for maintaining biodiversity, regulating hydrological processes, and supporting ecological functioning [4,5]. In September 2023, Zhejiang Province released the "Guidelines for Evaluating the Ecological Health of Lakes and Reservoirs in Zhejiang Province (Trial Implementation)", the first local-level technical document in our country [6], which further standardized the types, the methods for determining the width and

the ecological restoration technical measures of ecological riparian buffer zones. Since then, Zhejiang Province has carried out many demonstration projects for riparian zone restoration. Vegetation, as a vital component of riparian ecosystems, plays a crucial role in protecting biodiversity and maintaining the ecological functions of riparian zones [7,8]. Research priorities regarding riparian vegetation differ between China and other countries. International studies primarily focus on influencing factors of vegetation structure dynamics [9], corridor functions [10], and invasive species [11]. Although research in China started later, it has developed rapidly [12]. Current studies emphasize riparian flora and species diversity, vegetation structure and ecological functions, restoration techniques, interactions between riparian vegetation and environmental factors, and the physiological and ecological characteristics of vegetation [13,14]. In recent years, intensified human activities have severely disturbed riparian vegetation, increasing ecosystem fragility. Consequently, research on riparian vegetation has become a major focus.

Investigating key environmental factors influencing riparian vegetation diversity helps reveal the intrinsic mechanisms underlying the restoration and stable maintenance of riparian ecosystems. Riparian site conditions directly affect vegetation growth and spatial distribution, while vegetation growth processes alter soil properties, creating a bidirectional interaction. Additionally, riparian vegetation is influenced by river hydrological characteristics [15]. Environmental factors—including topographic elements (slope gradient, aspect, elevation) and soil properties (nutrients, moisture, organic matter content)—play crucial roles in vegetation growth and distribution [16]. Kong, Q.X. et al. [17] identified elevation as a significant environmental factor affecting vegetation diversity in the Huai River, Beijing. Zhang Zhiyong et al. [18] indicated that soil calcium–magnesium chelated phosphorus content is a key factor determining riparian plant community diversity in the Sanjiang River Basin. However, most scholars have examined the influence mechanisms of soil factors or aquatic environmental factors based on individual rivers, without fully considering how river characteristics affect the distribution patterns of riparian vegetation.

Compared to large rivers, small–medium rivers have smaller drainage basins (200–3000 km^2) but are more numerous, widely distributed, and ecologically significant. These rivers are predominantly located in mountainous and urban areas, where ecosystems face heightened pollution risks due to riverbed siltation and complex surrounding environments. As vital water carriers, small–medium rivers not only supply essential water for human production and daily life but also continuously replenish major rivers with water volume and nutrients, playing an irreplaceable role in water-shed water cycles and ecosystems [19].

In summary, most current research primarily focuses on major rivers and plains rivers, while studies on small–medium rivers remain insufficient. This study selected three adjacent small–medium rivers in the northern part of Longyou County, Zhejiang Province, as the research areas. The objectives of this study are: (1) to clarify the distribution characteristics of riparian vegetation at different scales (river and river segment scales). (2) to analyze the key factors influencing riparian vegetation distribution, including soil and water environment parameters, as well as hydrological characteristics. This study could improve the understanding the distribution mechanism of riparian vegetation diversity in small–medium rivers. It provides scientific basis for the restoration of riparian vegetation diversity and supports the construction of green ecological corridors along small–medium rivers.

2. Materials and Methods

2.1. Study Area

The study area is located in the northern watershed of Longyou County, Quzhou City, Zhejiang Province, China. It lies between 119°1′41″ E to 119°19′52″ E and 28°44′10″ N to 29°17′15″ N, belonging to the Qiantang River system. The total area of the watershed is approximately 392.4 km^2, with an elevation ranging from 60 to 250 m. The region has a subtropical monsoon climate with distinct basin characteristics. The long-term average temperature is 17.1 °C, with an annual maximum of 38 °C and an annual minimum of approximately −5 °C. The average annual precipitation is 1620 mm, with an annual runoff depth of approximately 900 mm, indicating relatively abundant water resources. However, precipitation distribution is uneven in both space and time due to the influence of frontal cyclones, typhoons, tropical storms, and terrain, with significant interannual and intra-annual variations. According to long-term observational data from the Longyou Rainfall Station, annual precipitation distribution aligns with the patterns of monsoon activity, with rainfall increasing monthly from January to March, with the rainy season occurring from April to September, during which April to June sees the most concentrated rainfall, making it highly prone to flooding disasters. After September, rainfall decreases monthly, increasing the likelihood of droughts. The distribution of runoff within the year is uneven, with the maximum monthly runoff typically occurring in June and the minimum monthly runoff usually occurring between August and December. The runoff from April to June accounts for approximately 53% of the annual runoff. The main water systems in the study area include the Tashi River (TSX), Zesui River (ZSX) and Mohuan River (MHX), whose locations and characteristics are shown in Figure 1, Tables 1 and 2.

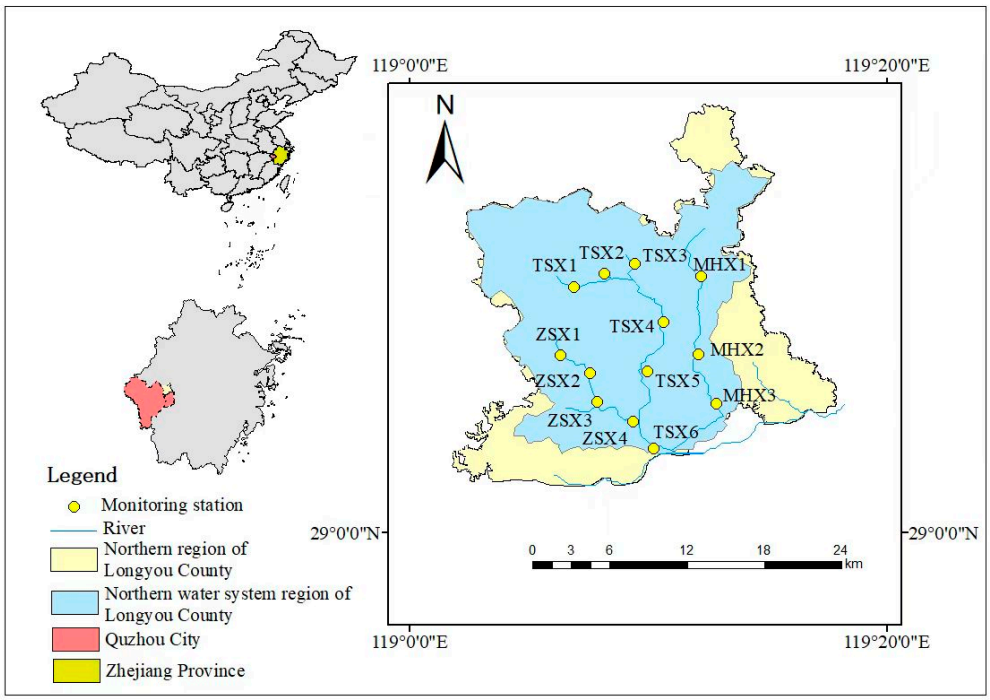


Figure 1. Schematic map of the geographical location of the research area and monitoring points.

Table 1. The characteristics of rivers in the study area.

River Name	River Length (km)	Water Area (ha)	Watershed Area (km^2)	Average Runoff Flow (m^3/s)	Average Monthly Flow in a Year with Abundant Rainfall (m^3/s)	Average Monthly Flow During Dry Years (m^3/s)
TSX	22.3	45.5	248	19.14	29.54	30.38
ZSX	16.2	16.1	125.5	1.21	2.04	1.62
MHX	15	24.8	102	26.61	93.04	100.19

Table 2. The characteristics of river segments in the study area.

River Name	River Section	Average Flow Velocity (cm/s)	Average Water Surface Width (m)	River Width (m)	Average Monthly Flow in a Year with Abundant Rainfall (m^3/s)	Average Monthly Flow During Dry Years (m^3/s)
TSX	S	11.43	4.23	11.	2.04	1.62
	Z	6.43	15.	24.75	28.99	29.70
	X	2.79	3	40	57.59	59.81
ZSX	S	3.30	4.5	10	2.04	1.62
	Z	13.96	6	18	2.04	1.62
	X	5.03	13	18	2.04	1.62
MHX	S	6.86	20	22	64.82	67.43
	Z	3.20	14	21	107.15	116.57
	X	2.63	16	18	107.15	116.57

In the table, S—upstream; Z—midstream; X—downstream.

2.2. Survey of Riparian Vegetation Composition and Diversity

The vegetation survey of riparian herbaceous of the three rivers (Tashi River, Zesui River, and Mohuan River, shown in Figure 1) in the northern of Longyou was conducted in May and October of 2023 and 2024, respectively, with a total of four survey periods. During each survey period, a total of 13 monitoring sites were set up along the riparian areas based on field investigations, with three vegetation survey samples (1 m × 1 m) being arranged in parallel along the riverbank at intervals of 5~10 m for each monitoring site.

Within each survey sample, field surveys recorded the plot cover, species name, as well as the vegetation number and cover for each species. Vegetation species identification was based on the "Flora of China" and the "Illustrated Guide to Higher Plants of China." The above-ground parts of the vegetation were collected, packaged, and returned to the laboratory as needed. After weighing, blanching, drying, reweighing the collected vegetation, fresh and dry biomass were determined for each species. Key statistical indicators at the species level included plant name, plant number, cover, and biomass. Key statistical indicators at the vegetation community level included total plot cover, number of species, diversity indices, and biomass per unit area.

2.3. Survey of Potential Impact Factors (Riparian Soil and Water Environmental Parameters)

After vegetation sampling was completed, surface litter was removed and soil was excavated (0–20 cm) and returned to the laboratory for soil profile analyses. Soil analyses included soil moisture content (SM), pH, soil organic matter (SOM), total nitrogen (STN), total phosphorus (STP), ammonium nitrogen (SNH_4^+-N), and nitrate nitrogen (SNO_3^--N). The determination methods are shown in Table 3.

Simultaneously, water samples were collected from the river section adjacent to the plot and stored in 500 milliliter bottles. Collected water samples were refrigerated in insulated boxes containing ice and transported to the laboratory. Standard methods were employed to analyze and determine corresponding water quality parameters, with a focus on monitoring ammonium nitrogen (WNH_4^+-N), nitrate nitrogen (WNO_3^--N), total nitrogen (WTN), total phosphorus (WTP), and potassium permanganate (WP) indicators. The determination method is shown in Table 4.

Table 3. Soil Sample Analysis Parameters and Methods [20].

Parameters	Analysis Methods
Soil moisture content (SM)	Oven-drying method (105 °C, 12 h)
Soil pH	Potentiometric method
Soil organic matter (SOM)	Potassium Di-chromate Titration Combined with External Heating Method
Soil total nitrogen (STN)	Kjeldahl method
Soil total phosphorus (STP)	Alkali Fusion Spectrophotometric Method for Molybdenum and Antimony
Soil ammonium nitrogen (SNH_4^+-N)	Spectrophotometric Extraction Method for Potassium Chloride Solution
Soil nitrate nitrogen (SNO_3^--N)	Spectrophotometric Extraction Method for Potassium Chloride Solution

Table 4. Water Sample Testing Parameters and Methods.

Parameters	Analysis Methods
Total nitrogen (WTN)	Alkaline Potassium Persulfate Digestion with Ultraviolet Spectrophotometry
Potassium permanganate (WP)	Acidic method
Total phosphorus (WTP)	Potassium Persulfate Digestion Combined with Molybdenum-Antimony Spectrophotometry
Ammonium nitrogen (WNH_4^+-N)	Nessler Reagent Spectrophotometric Method
Nitrate nitrogen (WNO_3^--N)	Ultraviolet Spectrophotometry

2.4. Data Processing and Statistical Analysis

2.4.1. Calculation of Vegetation Diversity Index

To order the differences in the distribution characteristics of plant communities in different river sections, richness of species (R), Shannon–Wiener index (H), and the Pielou uniformity index (J) were selected to characterize community species diversity [21]. Richness of species refers to the total number of species observed in a sample plot. The Shannon–Wiener index indicates species abundance, with higher values meaning greater species abundance and more even distribution. The Pielou uniformity index measures the uniformity of species distribution within a multi-species system. When all species exhibit comparable abundance, the evenness index approaches 1. Conversely, if certain species dominate significantly over others, the evenness index decreases [22].

2.4.2. Statistical Analysis

Tukey variance analysis was used to analyze the differences in riparian vegetation diversity indices under different river spaces and seasons (Origin 2024), with significant differences being identified at the 0.05 level. In addition, Principal Components Analysis (PCA) was used to extract principal components from all soil and water environmental factors (Origin 2024), which were identified as key influencing environmental factors. Finally, Pearson correlation analysis was employed to evaluate the relationships between riparian vegetation diversity indices and key environmental parameters.

3. Results and Discussion

3.1. Vegetation Classification Statistics

Based on two years of survey data, 55 families, 162 genera and 220 species of herbaceous vegetation were found in the riparian zones of the northern rivers in Longyou County. Among these, there were five species of ferns (Class Polypodiopsida), and 215 species of angiosperms, including 158 species of dicotyledons and 57 species of monocotyledons. The dominant families (each constituting >5% of the total species) included Poaceae (39 species, 17.73%), Asteraceae (32 species, 14.55%), Polygonaceae (15 species, 6.82%), and Lamiaceae (13 species, 5.91%). By season, there were 38 families, 99 genera, and 128 species of herbaceous vegetation recorded in summer, accounting for 58.18% of the total species.

In contrast, there were 48 families, 119 genera, and 150 species recorded in the autumn, accounting for 68.18% of the total species.

By river section (as shown in Tables 5 and 6), a total of 168 herbaceous vegetation species, belonging to 46 families and 132 genera, were recorded in the TSX, accounting for 76.36% of the total species. Poaceae (29 species) and Asteraceae (29 species) were the dominant families. Among these sections, the upper section contained 86 species from 29 families and 73 genera, accounting for 39.09% of the total species. Poaceae (21 species) and Asteraceae (12 species) were dominant here. The middle section contained 95 species from 35 families and 79 genera (43.18% of the total), with Poaceae (17 species) and Asteraceae (14 species) as the dominant families. The lower section contained the fewest species: 42 species from 18 families and 36 genera (19.09% of the total), where Asteraceae (11 species) and Poaceae (6 species) were dominant.

Table 5. Species composition of herbaceous vegetation at the river scale.

River Name	Species	Family	Genus	Percentage of Total Species (%)	Dominant Families
TSX	168	46	132	76.36	Poaceae (29 species), Asteraceae (29 species)
ZSX	78	29	66	35.45	Poaceae (20 species), Asteraceae (11 species), Polygonaceae (9 species)
MHX	77	27	66	35	Poaceae (16 species), Asteraceae (14 species), Polygonaceae (7 species)

Table 6. Species composition of herbaceous vegetation at the river segment scale.

River Name	River Section	Species	Family	Genus	Percentage of Total Species (%)	Dominant Families
TSX	S	86	29	73	39.09	Poaceae (21 species), Asteraceae (12 species)
	Z	95	35	79	43.18	Poaceae (17 species), Asteraceae (14 species)
	X	42	18	36	19.09	Asteraceae (11 species), Poaceae (6 species)
ZSX	S	52	21	43	23.64	Poaceae (12 species), Asteraceae (9 species)
	Z	32	15	29	14.55	Poaceae (9 species), Polygonaceae (6 species)
	X	26	15	25	11.82	Poaceae (8 species), Polygonaceae (3 species)
MHX	S	41	22	39	18.64	Poaceae (9 species), Asteraceae (8 species)
	Z	37	13	33	16.82	Poaceae (10 species), Polygonaceae (6 species), Asteraceae (4 species)
	X	35	14	31	15.91	Asteraceae (9 species), Poaceae (9 species)

In the table, S—upstream; Z—midstream; X—downstream.

By river section (as shown in Tables 5 and 6), a total of 168 herbaceous vegetation species, belonging to 46 families and 132 genera, were recorded in the TSX, accounting for 76.36% of the total species. Poaceae (29 species) and Asteraceae (29 species) were the dominant families. Among these sections, the upper section contained 86 species from 29 families and 73 genera, accounting for 39.09% of the total species. Poaceae (21 species) and Asteraceae (12 species) were dominant here. The middle section contained 95 species from 35 families and 79 genera (43.18% of the total), with Poaceae (17 species) and Asteraceae (14 species) as the dominant families. The lower section contained the fewest species: 42 species from 18 families and 36 genera (19.09% of the total), where Asteraceae (11 species) and Poaceae (6 species) were dominant.

In the Zesui River, 78 herbaceous vegetation species, belonging to 29 families and 66 genera, were recorded in the riparian zones, accounting for 35.45% of the total species. Poaceae (20 species), Asteraceae (11 species), and Polygonaceae (9 species) were identified as the dominant families. Among the river sections, the upper reaches contained 52 species from 21 families and 43 genera, representing 23.64% of the total species, with Poaceae (12 species) and Asteraceae (9 species) being predominant. The middle reaches contained 32 species from 15 families and 29 genera (14.55% of the total), where Poaceae (9 species) and Polygonaceae (6 species) were the dominant families. The lower reaches contained

26 species from 15 families and 25 genera (11.82% of the total), with Poaceae (8 species) and Polygonaceae (3 species) as the predominant families.

In the Mohuan River, 77 herbaceous vegetation species, belonging to 27 families and 66 genera, were recorded, accounting for 35% of the total species. Similar to the Zesui River, the dominant families were also Poaceae (16 species), Asteraceae (14 species) and Polygonaceae (7 species). Among the river sections, the upper reaches contained 41 species from 22 families and 39 genera, representing 18.64% of the total species, with Poaceae (9 species) and Asteraceae (8 species) being predominant. The middle reaches contained 37 species from 13 families and 33 genera (16.82% of the total), where Poaceae (10 species), Polygonaceae (6 species), and Asteraceae (4 species) were the dominant families. The lower reaches contained 35 species from 14 families and 31 genera (15.91% of the total), with Asteraceae (9 species) and Poaceae (9 species) as the predominant families.

Based on the above results, it was evident that riparian vegetation species in this region were concentrated within a few major families, such as Poaceae and Asteraceae, while most families contained only a few or even a single species. Riparian zones provided an environment characterized by frequent disturbances and abundant yet unstable moisture. Many grass and daisy family vegetation species are annual, capable of rapidly completing their entire life cycle—germination, growth, flowering, and seed production—within a brief suitable growing season [23]. Grass family vegetation possesses extensive root systems that transport oxygen from the aboveground parts to the roots, enabling survival in flooded, oxygen-depleted soils. Simultaneously, these roots can penetrate deeply into the soil to absorb water during droughts. The Asteraceae family occupies a broad ecological niche, adapting to the moisture gradient across the riparian zone from the water's edge to higher elevations. This indicates that both the diversity and distribution range of herbaceous vegetation communities in this region are relatively limited. The prevalence of single-species dominance further suggests that these vegetation species may undergo significant changes even in response to subtle variations in environmental conditions. Additionally, the number of herbaceous vegetation species in the downstream riparian zone of hilly rivers was consistently lower than in the middle and upper reaches. This finding aligns with the research results of other studies in regional rivers [24,25], likely attributable to changes in environmental and water flow conditions in the downstream reaches, as well as the increasing number of villages and associated anthropogenic disturbances.

3.2. Distribution Characteristics of Riparian Vegetation Biomass and Diversity at Different Scales

3.2.1. River Scale Distribution Characteristics

At the river scale, the herbaceous vegetation communities of the three rivers—Tashi River (TSX), Zesui River (ZSX), and Mohuan River (MHX)—exhibited significant spatial heterogeneity (as shown in Figure 2). Specifically, TSX exhibited biomass per unit area ranging from 138.49 to 409.06 g/m^2, Shannon's diversity index from 3.33 to 4.48, species richness from 95 to 109, and Pielou's evenness index from 0.93 to 0.95. In the ZSX area, biomass ranged from 170.74 to 408.21 g/m^2, Shannon's index from 2.06 to 3.26, species richness from 45 to 49, and Pielou's evenness index from 0.63 to 0.75. The MHX area recorded biomass ranging from 110.68 to 546.28 g/m^2, with Shan-non indices between 2.53 and 3.00, species counts from 41 to 50, and Pielou's evenness indices from 0.80 to 0.82. Compared to a nearby study area (Xu Kejun et al.'s research in the Lingshan River region of Quzhou City, Zhejiang Province) [26], this region exhibited significantly higher Shannon indices and richness of species than the Lingshan River area, indicating a higher level of biodiversity. Additionally, the Pielou's evenness index consistently exceeded 0.6 across all three rivers. This indicates relatively uniform distribution of individual numbers among different vegetation species within riparian communities, with no single or few dominant

species completely dominating. Consequently, no clearly dominant species were identified among the herbaceous vegetation in the riparian zones of this area.

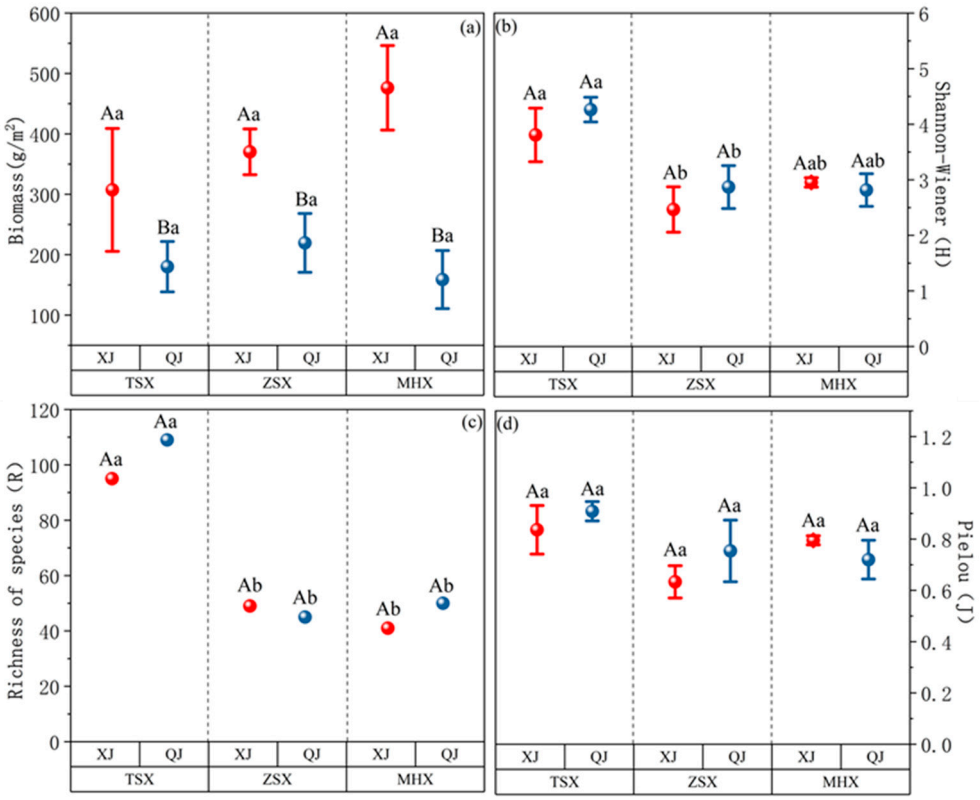


Figure 2. Distribution of riparian vegetation biomass (**a**), Shannon-Wiener index (**b**), richness of species (**c**), and Pielou (**d**) with different seasons and rivers. Different capital letters indicate significant differences between seasons, while different lowercase letters indicate significant differences between rivers. The results indicate significant differences at the 0.05 significance level. XJ—Summer season. QJ—Autumn season. TSX—Tashi River. ZSX—Zesui River. MHX—Mohuan River.

Comparing the three rivers, TSX exhibited significantly higher Shannon diversity indices and richness of species, while biomass per unit area and Pielou's evenness indices showed no significant differences among the rivers. The TSX section demonstrated the highest Shannon diversity and richness of species, indicating its riparian zone supported a greater number of herbaceous vegetation species. This phenomenon may be attributed to the larger water volume and wider riparian zone width of TSX. As the largest tributary in the region, TSX possessed a highly heterogeneous physical environment, providing opportunities for coexistence among more vegetation species. This ultimately manifested as higher Shannon–Wiener diversity indices and richness of species.

From a seasonal perspective, the biomass of riparian herbaceous vegetation was significantly higher in summer than in autumn. Furthermore, seasonal dynamics of riparian vegetation communities varied across different rivers: for instance, all TSX indices were lower in summer than in autumn, while the ZSX richness of species index and Pielou's evenness index were higher in summer. However, no significant differences were observed in seasonal dynamics across all indices. Significant seasonal differences were observed only in biomass. This is because the study area experiences a wet season during summer, with abundant soil moisture providing the foundation for rapid biomass accumulation. In contrast, autumn marks the onset of the dry season, characterized by declining water levels and reduced soil moisture, which fails to meet vegetation's water requirements. Vegetation struggles to sustain summer's rapid growth, causing biomass accumulation rates to sharply

decline. Thus, the pronounced seasonal variation in riparian biomass between summer and autumn exemplifies its nature as a highly dynamic, water-level-driven ecosystem [27].

3.2.2. River Segment Scale Distribution Characteristics

At the river segment scale, biomass, the Shannon diversity index, species richness, and Pielou's evenness index exhibited significant spatial variation across different segments of the Tashi River, Zeshui River, and Mohuan River (as shown in Figure 3). In the summer, the upper reaches of the Tashi River exhibited the highest biomass (424.75 ± 38.29 g/m^2) and Shannon index (3.66 ± 0.08). The middle reaches had the lowest biomass (213.12 ± 26.95 g/m^2), while the lower reaches recorded the lowest species richness (20 species). In autumn, the upstream section maintained the highest biomass (218.99 ± 17.74 g/m^2) and diversity (3.99 ± 0.26), while the downstream section had the lowest biomass (143.59 ± 39.6 g/m^2). In the summer, the middle reaches exhibited the highest biomass (402.06 ± 80.34 g/m^2), while the Shannon diversity index and species richness decreased from upstream to downstream. In autumn, the upstream section had the highest biomass (285.78 ± 55.12 g/m^2) and Shannon diversity index (2.86 ± 0.07), whereas the downstream section had the lowest biomass (183.11 ± 31.45 g/m^2). For MHX, the middle reaches had the highest biomass in summer (546.68 ± 56.45 g/m^2), but the lower reaches had the highest biomass in autumn (224.05 ± 66.24 g/m^2). In autumn, the Shannon index in the upstream section (2.96 ± 0.05) was significantly higher than that in the middle section (1.76 ± 0.09).

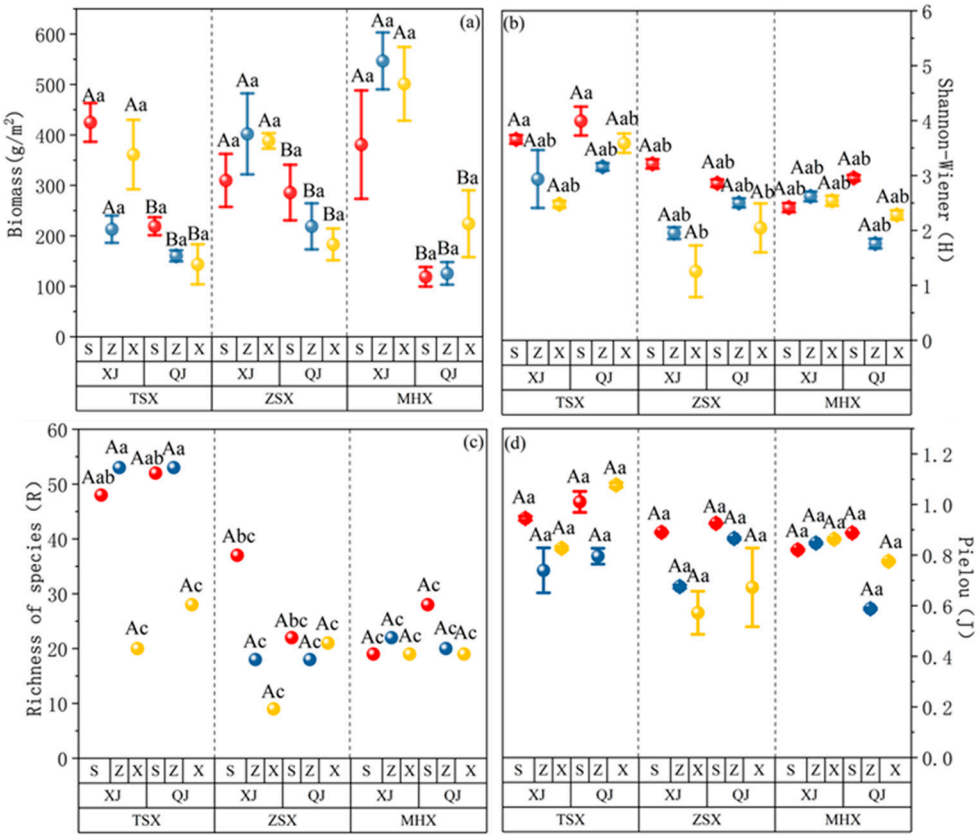


Figure 3. Distribution of riparian vegetation biomass (**a**), Shannon-Wiener index (**b**), richness of species (**c**), and Pielou (**d**) with different seasons and river sections. Different capital letters indicate significant differences between seasons, while different lowercase letters indicate significant differences between different river segments in the same river. The results indicate significant differences at the 0.05 significance level. S—upstream. Z—midstream. X—downstream. XJ—Summer season. QJ—Autumn season. TSX—Tashi River. ZSX—Zesui River. MHX—Mohuan River.

Tukey's test indicated that the Shannon index and species richness in the upper reaches of the TSX exhibited significant differences across multiple river segments, while the evenness index showed no significant variation. Overall, the upper reaches generally exhibited higher diversity and species richness, which is likely due to reduced human disturbance and more stable natural conditions. In contrast, the middle and lower reaches have undergone significant alterations due to human activities, resulting in unstable herbaceous plant communities. Field investigations revealed that the middle reaches flowed through villages, where domestic waste and sewage severely degraded the riparian environment. The lower reaches are frequently used for fishing, and their narrow riparian strip width significantly reduces vegetation diversity. Clearly, environmental degradation caused by human activities is a major driver of reduced species diversity. Additionally, biomass distribution across different river sections was significantly affected by season and river conditions, with summer biomass being markedly higher than in autumn. In summary, the primary causes of variation in species diversity among river sections are differences in hydrological conditions and soil characteristics from upstream to downstream, coupled with varying degrees of human disturbance.

3.3. Multi-Scale Distribution Mechanism of Riparian Vegetation

3.3.1. Environmental Factors Affecting Vegetation Distribution at the River Scale

The principal component analysis results (as shown in Figure 4) indicated that the cumulative variance explained by the first two principal components reached 70.1% during summer. In the first principal component (40.2%), SM (0.39), SOM (0.37), STP (0.37), SNH_4^+-N (0.32), and SNO_3-N (0.28) exhibited longer projections on the PC1 axis, indicating significant positive correlations among these factors. Conversely, WP (−0.41) and WTN (−0.36) showed significant negative correlations. The second principal component (29.9%) primarily reflected water body environmental factors including WTP (0.45) and WNH_4^+-N (0.49). The principal component structure underwent significant changes in autumn: PC1 explained 45.7% of the variance, PC2 explained 22.9%, and together they accounted for 68.6% of the variance. The primary factor (45.7%) was mainly driven by SNH_4^+-N (0.36), SOM (0.35), and WP (0.35), which showed significant positive correlations, while WTN (−0.37), WNH_4^e-N (−0.36), and WTN (−0.32) showed negative correlations. In the second principal component (22.9%), WNO_3-N (0.55) and SM (0.4) exhibited high loadings.

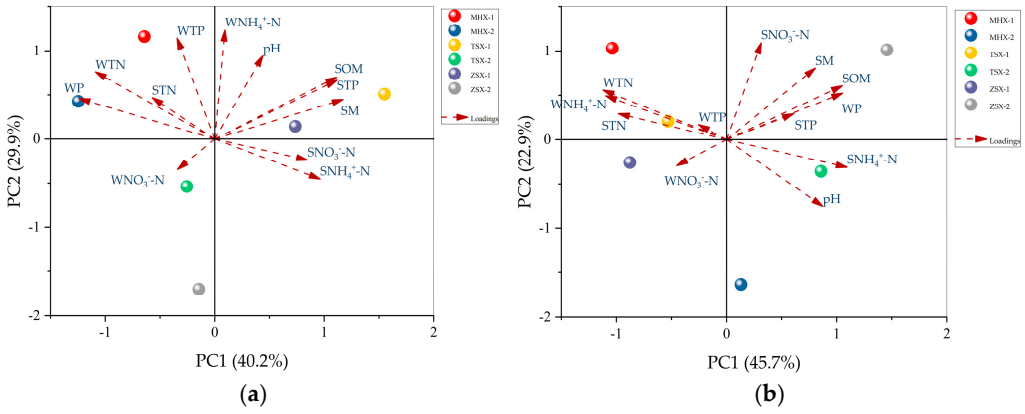


Figure 4. PCA analysis of environmental factors at the river scale in (**a**) summer and (**b**) autumn. SM—soil moisture content. SOM—organic matter. STN—total nitrogen. STP—total phosphorus. NH_4^+-N—ammonium nitrogen. NO_3^--N—nitrate nitrogen. WNH_4^+-N—water ammonium nitrogen. WNO_3^--N—water nitrate nitrogen. WTN—water total nitrogen. WTP—water total phosphorus. WP—potassium permanganate.

Furthermore, correlation analysis between key environmental factors and vegetation biomass and diversity (see Tables 7 and 8) revealed that the summer riparian herbaceous vegetation biomass per unit area (W) showed a significant positive correlation with SOM ($p < 0.01$). Shannon–Wiener index (H) correlated positively with SOM and WNH_4^+-N ($p < 0.05$). Richness of species (R) showed a significant positive correlation with SNO_3-N ($p < 0.01$) and a positive correlation with SNH_4^+-N ($p < 0.05$). The evenness index (J) exhibited a significant positive correlation with SOM ($p < 0.01$). In autumn, the Shannon–Wiener index (H) showed a positive correlation with WTN ($p < 0.05$). The evenness index (J) exhibited a significant positive correlation with WTN ($p < 0.01$) and a positive correlation with WNH_4^+-N ($p < 0.05$).

Table 7. Correlation between Riparian Vegetation Diversity Index and Key Soil–Water Physicochemical Properties at the River Scale during Summer.

		Biomass (g/m^2)	Shannon–Wiener	Richness of Species	Pielou
First principal component	SM	0.7	0.69	0.46	0.72
	SOM	0.86 **	0.85 *	0.32	0.87 **
	STP	0.78	0.77	0.40	0.78
	SNH_4^+-N	0.37	0.30	0.85 *	0.46
	SNO_3-N	0.36	0.33	0.87 **	0.44
	WP	0.62	0.51	0.58	0.66
	WTN	0.36	0.17	0.58	0.44
Second principal component	WTP	0.41	0.43	0.16	0.36
	WNH_4^+-N	0.76	0.82 *	0.54	0.72

* indicates significant correlation at the 0.05 level and ** indicates significant correlation at the 0.01 level.

Table 8. Correlation between Riparian Vegetation Diversity Index and Key Soil–Water Physicochemical Properties at the River Scale in Autumn.

		Biomass (g/m^2)	Shannon–Wiener	Richness of Species	Pielou
First principal component	SNH_4^+-N	0.78	0.72	0.44	0.81
	SOM	0.78	0.62	0.49	0.67
	WP	0.67	0.64	0.46	0.69
	WTN	0.77	0.82 *	0.64	0.86 **
	WNH_4^+-N	0.78	0.80	0.64	0.84 *
	STN	0.59	0.74	0.5	0.8
Second principal component	SNO_3-N	0.36	0.49	0.6	0.37
	SM	0.56	0.42	0.16	0.52

* indicates significant correlation at the 0.05 level and ** indicates significant correlation at the 0.01 level.

Based on the above findings, soil organic matter and nitrogen content in water bodies were key environmental factors driving the structure and diversity of herbaceous vegetation communities in this riparian zone. Soils with high organic matter content typically exhibit superior water and nutrient retention capabilities, providing vegetation with more abundant nutrients and a better rhizosphere environment, thereby supporting higher biomass accumulation. Simultaneously, soil organic matter creates more diverse microhabitats and resource gradients, allowing for the coexistence of species occupying different ecological niches and thereby increasing overall community diversity [28]. Therefore, protecting and enhancing soil organic matter content in riparian zones represents a critical management measure for maintaining the health and functionality of this ecosystem.

Soil available nitrogen (nitrate and ammonium nitrogen) content showed a significant positive correlation with species richness. The indicates that higher nitrogen availability enables ecosystems to support the nutritional demands of more species, directly increasing species abundance [29]. Vegetation evenness exhibits extremely high correlations with soil organic matter and water nitrogen, likely preventing any single vegetation species or

group from gaining absolute dominance in resource competition (e.g., grasses readily form dominant monocommunities in nutrient-poor soils) [30]. Uniform nutrient supply enables more balanced resource utilization across species, thereby enhancing community evenness and structural stability.

Furthermore, autumn correlation analyses revealed that riparian vegetation biomass and diversity exhibited stronger correlations with aquatic environmental factors. This indicates that autumn, as the terminal phase of vegetation growth, places greater emphasis on nutrient exchange processes between water and soil for vegetation development.

3.3.2. Environmental Factors Affecting Vegetation Distribution at the River Segment Scale

Principal component analysis (as shown in Figure 5) indicated that the summer and autumn principal components extracted at the river segment scale explain 60.8% and 62.8% of the variance in environmental factors, respectively. On the first principal component (explaining 38.9% variance) for summer, SM (0.41), SNH_4^+-N (0.41), and WNO_3^--N (0.33) exhibited longer projections on the positive half-axis of PC1, while WTN (−0.38) and WTP (−0.32) showed longer projections on the negative half-axis of PC1. In the second principal component (21.9%), STN (0.49), STP (0.47), pH (0.46), and WNH_4^+-N (0.35) showed significant positive correlations. In autumn, the first principal component explained 44% of the variance, effectively reflecting the influence of environmental factors on vegetation diversity along the PC1 axis. It showed significant positive correlations with WTP (0.40), WNH_4^+-N (0.32), and WNO_3^--N, and negative correlations with WP (−0.38) and SM (−0.33). The second principal component explained 18.8% of the variance, primarily driven by SOM (0.54), STN (0.51), and STP (0.42), and negatively correlated with pH (−0.37).

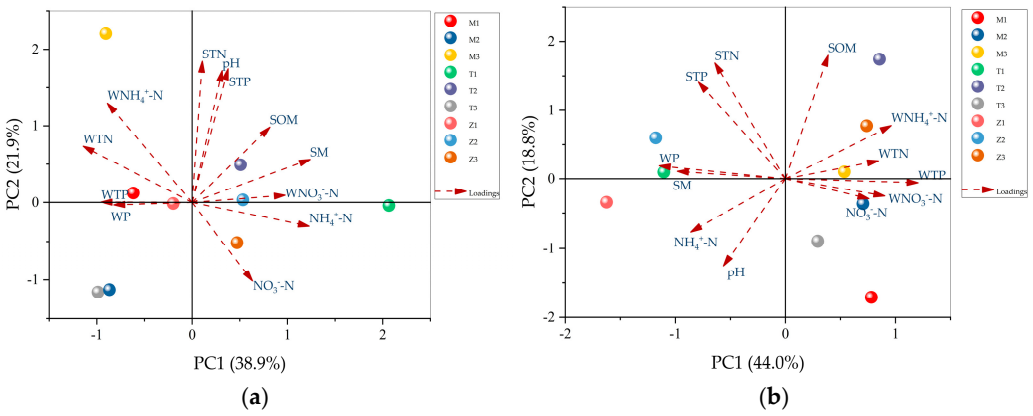


Figure 5. PCA analysis of environmental factors at the river segment scale in (**a**) summer and (**b**) autumn. SM—soil moisture content. SOM—organic matter. STN—total nitrogen. STP—total phosphorus. NH_4^+-N—ammonium nitrogen. NO_3^--N—nitrate nitrogen. WNH_4^+-N—water ammonium nitrogen. WNO_3^--N—water nitrate nitrogen. WTN—water total nitrogen. WTP—water total phosphorus. WP—potassium permanganate.

Correlation analysis between key environmental factors and riparian vegetation biomass and diversity (see Tables 9 and 10) revealed that both the summer Shannon–Wiener index and species richness showed significant positive correlations ($p < 0.01$) with water body nitrate nitrogen. Autumn biomass exhibited positive correlations ($p < 0.05$) with soil moisture content, water body total phosphorus, and water body nitrate nitrogen.

Table 9. Correlation between riparian vegetation diversity indexes and soil–water physicochemical properties under river segment-scale in summer.

		Biomass (g/m^2)	Shannon–Wiener	Richness of Species	Pielou
First principal component	SM	0.18	0.53	0.65	0.25
	SNH_4^+-N	0.28	0.57	0.66	0.33
	WNO_3-N	0.53	0.82 **	0.81 **	0.73
	WTP	0.27	0.30	0.42	0.24
	WTN	0.50	0.62	0.58	0.50
Second principal component	STN	0.32	0.26	0.13	0.38
	WNH_4^+-N	0.65	0.24	0.41	0.28
	STP	0.61	0.16	0.54	0.50
	Ph	0.24	0.43	0.51	0.27

** indicates significant correlation at the 0.01 level.

Table 10. Correlation between riparian vegetation diversity indexes and soil–water physicochemical properties under river segment-scale in autumn.

		Biomass (g/m^2)	Shannon–Wiener	Richness of Species	Pielou
First principal component	SM	0.79 *	0.32	0.13	0.41
	WNH_4^+-N	0.70	0.58	0.29	0.71
	WNO_3-N	0.79 *	0.56	0.40	0.59
	WP	0.73	0.39	0.32	0.56
	WTP	0.82 *	0.39	0.10	0.49
Second principal component	SOM	0.69	0.36	0.35	0.39
	STN	0.41	0.19	0.44	0.24
	STP	0.18	0.25	0.53	0.45
	Ph	0.71	0.46	0.14	0.60

* indicates significant correlation at the 0.05 level.

The results indicated that at the river segment scale, the correlation between vegetation diversity and soil physicochemical properties was not significant. The primary reason is the high gravel content in the surface soil of this riparian zone, which leads to low surface soil heterogeneity. This, in turn, results in insignificant correlations between vegetation diversity indices and various soil physicochemical indicators, consistent with the findings of Xia et al. [31] in the Huai River, Beijing. Most current studies on the diversity of riparian herbaceous vegetation and associated environmental factors have focused primarily on vegetation and soil physical and chemical properties. During this field survey, it was noted that the riparian zones in the study area were relatively narrow, with vegetation growing close to the water. The above results validated this hypothesis, indicating that vegetation diversity exhibits a stronger correlation with aquatic environmental factors. As a critical ecological transition zone between terrestrial and aquatic ecosystems, riparian zones serve as core conduits for material cycling and energy flow. Rivers and other water bodies, along with soils influenced by flowing water, form the foundation of ecological processes [3]. Essentially, the vegetation–soil–water system functions holistically to maintain ecosystem dynamic stability. Therefore, at the river segment scale, the diversity of riparian herbaceous vegetation is more influenced by aquatic environmental factors, with total phosphorus and nitrate nitrogen concentrations in the water body emerging as the primary determinants.

3.3.3. Relations Between Vegetation Distribution and Hydrological Characteristics

Through an analysis of the correlation between riparian vegetation and river characteristics in the northern water system of Longyou (as shown in Figure 6), it can be observed that at the river segment scale, the vegetation richness index was positively correlated with the Shannon diversity index, while the Shannon diversity index showed a significant positive correlation with the evenness index. This indicates that as species richness in-

creases, the community structure becomes more complex and species distribution becomes more uniform. Additionally, river width and water surface width exhibited a significant positive correlation, reflecting consistency in hydrological morphological characteristics. At the river scale, the evenness index was positively correlated with water area, suggesting that larger water bodies may provide a more balanced habitat for vegetation. Meanwhile, river length and watershed area show a significant positive correlation, consistent with the fundamental principles of watershed morphological development in hydrological geography.

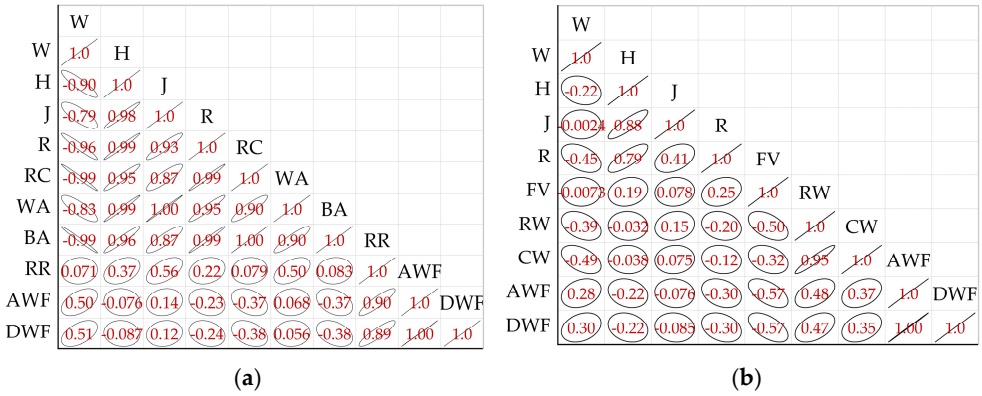


Figure 6. The correlation between vegetation and water environment at different scales: (**a**) the river scale; (**b**) the river segment scale. W—Biomass. H—Shannon–Wiener. J—Pielou. R—Richness of species. RC—River Length. WA—Water Area. BA—Watershed Area. RR—Runoff Flow. AWF—Average monthly flow in a year with abundant rainfall. DWF—Average monthly flow during dry years. FV—Flow Velocity. RW—Water Surface Width. CW—Channel Width.

Vegetation, as an important component of riparian ecosystems, influences water environments through various pathways. Conversely, riparian hydrological processes exert critical regulatory effects on vegetation cover, species composition, primary productivity, and material–energy cycles, with their changes significantly impacting the long-term stability of ecosystem structure and function. The two are mutually reinforcing, forming a bidirectional feedback mechanism. Taking water level fluctuations as an example, in riparian wetland ecosystems, high water levels can lead to the mass extinction of dominant species. Conversely, water level declines provide ecological niches for the germination and growth of various species. Since woody vegetation has longer life cycles and cannot complete its establishment process during brief receding water periods, it is often replaced by short-lived herbaceous vegetation. This periodic hydrological fluctuation ultimately shapes the extensive herbaceous wetland community structure along river and lake shorelines, serving as a crucial mechanism for maintaining wetland biodiversity [32].

The tributaries in the northern region of Longyou are all rainfed mountain streams characterized by short flow paths, rapid currents, steep gradients, abrupt water level changes, unpredictable discharge, and significant variations between dry and flood seasons, with a strong influence from seasonal rainfall. During the flood season, mountainous river channels experience sudden, rapid rises and falls in water level, carrying large amounts of gravel and sand downstream, which settle and raise the riverbed, affecting flood discharge and the ecological environment. Additionally, river sections with low vegetation coverage along the banks are more prone to "sudden rises and rapid declines" in water levels, while riverbanks with high vegetation diversity can mitigate such extreme hydrological fluctuations [33]. Furthermore, studies have shown that flow rate is a primary factor influencing ecological changes in riparian vegetation [34–36]. During the dry season, the northern water system of Longyou experiences very low river flow rates, often resulting in intermit-

tent flow or drying up, failing to maintain the minimum flow rate necessary for a healthy aquatic environment. Due to human activities affecting water quality, ecological flow in rivers during the dry season is difficult to guarantee, leading to ecological degradation. This necessitates reservoir ecological scheduling or inter-basin water transfers to ensure the minimum ecological flow during the dry season. Therefore, investigating the coupled relationship between watershed morphological characteristics and biodiversity indicators at different scales can provide scientific basis for the protection and restoration of riparian ecosystems.

4. Conclusions

These results are expected to serve as a vital foundational resource, contributing to the restoration of plant diversity and the maintain sustainable ecological functions in riparian areas.

(1) In total, riparian vegetation surveys from three streams in Longyou County, China over a two-year period found 220 species of herbaceous plants belonging to 162 genera and 55 families. Meanwhile, herbaceous vegetation species were predominantly concentrated in a few families, with Poaceae (17.73%) and Asteraceae (14.55%) showing significant dominance. Additionally, autumn herbaceous species richness exceeded that of summer, while species richness in the downstream riparian zones of all three rivers consistently lagged behind their mid- and upstream counterparts.

(2) The herbaceous biomass and diversity along riparian zones exhibited significant variation across seasons and spatial scales of the rivers. At the river scale, the TSX River (the largest river in the study area) showed the highest herbaceous diversity index. At the river segment scale, the upper reaches exhibited higher diversity and abundance. Furthermore, herbaceous vegetation biomass along riparian zones was significantly influenced by seasonal factors.

(3) This study revealed that key environmental factors influencing vegetation distribution differed across scales. At the river scale, soil organic matter and water nitrogen were key factors influencing vegetation diversity. At the same time, the diversity of riparian vegetation was also affected by the water area. At the river segment scale, riparian herbaceous diversity was more influenced by aquatic environmental factors, with total phosphorus and nitrate nitrogen content in water bodies being the main determining factors.

Furthermore, this study focused solely on herbaceous vegetation and did not include woody vegetation communities, making it difficult to fully reflect the overall composition and structural characteristics of riparian vegetation. Future research could extend to woody vegetation to gain a more comprehensive understanding of riparian vegetation community structure and ecological functions.

Author Contributions: L.S., J.X. (Jihong Xia) and S.D. conceived and designed the experiments; H.Z., J.X. (Jiaxin Xu), F.S. and Y.L. performed the experiments; H.Z. and L.S. analyzed the data and wrote this paper. J.X. (Jihong Xia) and S.D. reviewed this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Nature Science Foundation of China (No. 52309047), the Open Research Fund of State Key Laboratory of Simulation and Regulation of Water Cycle in River Basins (China Institute of Water Resources and Hydropower Research) (No. IWHR-SKL-KF202301), and the Water Science Project of Foxiang Reservoir Engineering (No. ZJZHGL2023-018).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Liu, J.L.; Cheng, F.Y.; Zhu, Y.; Yang, Y.; Zhang, S.H. Urban land-use type influences summertime water quality in small and medium-sized urban rivers: A case study in Shanghai, China. *Land* **2022**, *11*, 511. (In Chinese with English Abstract). [CrossRef]
2. Signorile, A.; Saracino, R.; Dani, A.; Migliorini Giovannini, M.R.; Preti, F. Riparian vegetation surveys for roughness estimation. *Ecol. Eng.* **2024**, *209*, 107414. [CrossRef]
3. Han, L.; Wang, H.Z.; Yv, J. Research progress and prospects on riparian zone ecology. *Ecol. Environ. Sci.* **2013**, *22*, 879–886. (In Chinese with English Abstract).
4. Elliott, K.J.; Vose, J.M. Effects of riparian zone buffer widths on vegetation diversity in southern Appalachian headwater catchments. *For. Ecol. Manag.* **2016**, *376*, 9–23. [CrossRef]
5. Xiang, H.; Zhang, Y.; Richardson, J.S. Importance of riparian zone: Effects of resource availability at land-water interface. *Riparian Ecol. Conserv.* **2017**, *3*, 1–17. (In Chinese with English Abstract). [CrossRef]
6. Zhejiang Provincial Department of Ecology and Environment. Guidelines for Assessing Lake and Reservoir Aquatic Ecological Health in Zhejiang Province (Trial). [EB/OL]. (2023-09-15). [2023-10-23]. Available online: https://sthjt.zj.gov.cn/art/2023/10/23/art_1229263469_2493820.html (accessed on 22 September 2025).
7. Picco, L.; Sitzia, T.; Mao, L.; Comiti, F.; Lenzi, M.A. Linking riparian woody communities and fluviomorphological characteristics in a regulated gravel-bed river (Piave River, Northern Italy). *Ecohydrology* **2016**, *9*, 101–112. [CrossRef]
8. Garssen, A.G.; Baattrup-Pedersen, A.; Voesenek, L.A.C.J.; Verhoeven, J.T.A.; Soons, M.B. Riparian plant community responses to increased flooding: A meta-analysis. *Glob. Change Biol.* **2015**, *21*, 2881–2890. [CrossRef]
9. Denning, P.; Schulte, S. Integrative Review of Riparian Buffers Benefits in Urbanized Watersheds. *Midwest. J. Undergrad. Sci.* **2024**, *3*, 24–28. [CrossRef]
10. Fonseca, A.; Ugille, J.-P.; Michez, A.; Rodríguez-González, P.M.; Duarte, G.; Ferreira, M.T.; Fernandes, M.R. Assessing the Connectivity of Riparian Forests across a Gradient of Human Disturbance: The Potential of Copernicus "Riparian Zones" in Two Hydroregions. *Forests* **2021**, *12*, 674. [CrossRef]
11. Zelnik, I.; Mavrič Klenovšek, V.; Gaberščik, A. Complex Undisturbed Riparian Zones Are Resistant to Colonisation by Invasive Alien Plant Species. *Water* **2020**, *12*, 345. [CrossRef]
12. Wu, X.Q.; Fan, B.S.; Teng, Y.W.; Li, R.Q.; Qu, K.Y.; Qian, J.P.; Tian, B. Relationship between distribution characteristics of herbaceous plant communities and soil environmental factors in the riparian zone of Baiyangdian Watershed. *Chin. J. Appl. Environ. Biol.* **2022**, *28*, 1608–1614. (In Chinese with English Abstract).
13. Lou, Y.; Pan, Y.; Gao, C.; Jiang, M.; Lu, X.; Xu, Y.J. Response of plant height, species richness and aboveground biomass to flooding gradient along vegetation zones in floodplain wetlands, Northeast China. *PLoS ONE* **2016**, *11*, e0153972. (In Chinese with English Abstract). [CrossRef]
14. Moura, E.G.; Pott, A.; Severi, W.; Zickel, C.S. Response of aquatic macrophyte biomass to limnological changes under water level fluctuation in tropical reservoirs. *Braz. J. Biol.* **2019**, *79*, 120–126. [CrossRef] [PubMed]
15. Pielech, R.; Anioł-Kwiatkowska, J.; Szczęśniak, E. Landscape-scale factors driving plant species composition in mountain streamside and spring riparian forests. *For. Ecol. Manag.* **2015**, *347*, 217–227. [CrossRef]
16. Ahmad, S.S.; Shabbir, R.; Ahmed, M.N.; Wahid, A. Environmental diversification and spatial variations in riparian vegetation: A case study of Korang River, Islamabad. *Pak. J. Bot.* **2014**, *46*, 1203–1210.
17. Kong, Q.X.; Xin, Z.B.; Xia, X.P. Analysis of plant diversity and influencing factors in the riverbank zone of the Huai River in Beijing. *Sci. Technol. Rev.* **2017**, *35*, 57–65.
18. Zhang, Z.Y.; Liu, H.; Dong, F.Y.; Wang, L.; Chen, Y. Spatial distribution characteristics of plant communities along the banks of the Three Rivers Source Region and analysis of their driving factors. *Environ. Sci.* **2024**, *45*, 5351–5360. (In Chinese with English Abstract).
19. Su, Y.; Li, W.; Liu, L.; Huang, W.; Wu, J.; Yang, Z. Health assessment of small-to-medium sized rivers: Comparison between comprehensive indicator method and biological monitoring method. *Ecol. Indic.* **2021**, *126*, 107686. (In Chinese with English Abstract). [CrossRef]
20. Bao, S.D. *Soil Agro-Chemistrical Analysis*, 3rd ed.; China Agriculture Press: Beijing, China, 2000; pp. 22–74.
21. Shannon, C.E.; Weaver, W. *The Mathematical Theory of Communication*; University of Illinois Press: Urbana, IL, USA, 1963.
22. Pielou, E.C. Species diversity and pattern diversity in the study of ecological succession. *J. Theor. Biol.* **1966**, *10*, 370–383. [CrossRef]

23. Ling, L.; Yan, S.J.; Guan, Y.X.; Sun, Y.T.; Huang, Z.H.; Hu, K.H. Species composition and diversity distribution characteristics of riparian vegetation communities. *World For. Res.* **2023**, *36*, 27–33. (In Chinese with English Abstract).
24. Yang, J.Y.; Zhang, Y.; Wu, H.L.; Wang, X.Y.; Li, Y. Investigation and analysis of the current status of the inflowing rivers into Baiyangdian Lake. *China Water Resour.* **2021**, *11*, 35–37. (In Chinese with English Abstract).
25. Bao, Y.L.; Tian, B.; Zhang, Y.; Liu, X.; Li, F. Evaluation of river health in the Xiongan New Area. *Acta Ecol. Sin.* **2021**, *41*, 5988–5997. (In Chinese with English Abstract).
26. Xu, K.; Xia, J.; Sheng, L.; Wang, Y.; Zu, J.; Wang, Q.; Ji, S. Spatial Distribution Heterogeneity of Riparian Plant Communities and Their Environmental Interpretation in Hillstreams. *Appl. Sci.* **2024**, *14*, 5114. [CrossRef]
27. Mei, Y.; Huang, P.; Wang, P.; Zhu, K. Interactive effects of water level fluctuation and vegetation restoration on soil prokaryotic microbial community structure in the water-level fluctuation zone of the Three Gorges Reservoir. *Environ. Sci.* **2024**, *45*, 2715–2726.
28. Li, W.; Siddique, M.S.; Liu, M.; Graham, N.; Yu, W. The migration and microbiological degradation of dissolved organic matter in riparian soils. *Water Res.* **2022**, *224*, 119080. [CrossRef] [PubMed]
29. Zhou, X.; Tao, Y.; Yin, B.; Tucker, C.; Zhang, Y. Nitrogen pools in soil covered by biological soil crusts of different successional stages in a temperate desert in Central Asia. *Geoderma* **2020**, *366*, 114166. (In Chinese with English Abstract). [CrossRef]
30. Cui, P.P.; Yu, Y.; Qu, B.; Su, F.L. Effects of Enclosure on Plant Diversity and Vegetation Landscape in Degraded Riparian Grassland. *Ecol. Environ. Sci.* **2024**, *33*, 1708–1716.
31. Xia, X.P.; Xin, Z.B.; Kong, Q.X.; Zhang, J.; Yang, X. Differences in vegetation and soil physical and chemical properties along the banks of the Huai River in Beijing. *Chin. J. Soil Water Conserv.* **2017**, *15*, 117–124. (In Chinese with English Abstract).
32. Bao, Y.; Gao, P.; He, X. The water-level fluctuation zone of Three Gorges Reservoir—A unique geomorphological unit. *Earth-Sci. Rev.* **2015**, *150*, 14–24. (In Chinese with English Abstract). [CrossRef]
33. Kiss, T.; Fehérváry, I. Increased Riparian Vegetation Density and Its Effect on Flow Conditions. *Sustainability* **2023**, *15*, 12615. [CrossRef]
34. Guo, M.; Xue, W.L.; Wang, C.; Li, W.Z.; Gao, H.; Saintilan, N.; Li, C.L.; Huang, G.; Wang, Y.Y. Environmental Flow Increases The Riparian Vegetation Diversity and Community Similarity. *Wetlands* **2024**, *44*, 57. [CrossRef]
35. Bae, I.; Ji, U.; Järvelä, J.; Västilä, K. Blockage effect of emergent riparian vegetation patches on river flow. *J. Hydrol.* **2024**, *635*, 131197. [CrossRef]
36. Ye, M.; Hu, H.; Wu, P.; Xie, Z.; Hu, Y.; Lu, X. Ecological responses to hydrological connectivity in grassland riparian zones: Insights from vegetation and ground-dwelling arthropods. *Sci. Total Environ.* **2024**, *922*, 171196. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.