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Spatial Distribution Heterogeneity of Riparian Plant Communities and Their Environmental Interpretation in Hillstreams

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Abstract: In plant ecology and environmental remediation, the characterization of riparian plant communities and the influence of environmental factors have been widely discussed. However, the delineation of plant communities from different spatial perspectives is often overlooked, especially in hillstreams. In this study, the Lingshan River is taken as the research area, which is a quintessential hillstream and is characterized by a plethora of hydraulic structures lining its course by 20 weirs. We aim to investigate the multidimensional spatial distribution of riparian plants and their main environmental factors through plant field surveys combined with cluster analysis and redundancy analysis (RDA). The main findings are as follows: (1) In this study, a total of 104 herbaceous species were investigated, distributed among 12 families, in which Poaceae (16.67%) and Compositae (9.65%) showed significant dominance. (2) Plant community delineation was based on the complete linkage clustering. Five plant communities were classified along the longitudinal scale of the river, four plant communities were in the near-water zones, and three plant communities were in the far-water zones. (3) Riparian plant diversity and community distribution in longitudinal and lateral dimensions exhibits significant differentiation. Longitudinally, there was a significant decrease in plant diversity from upstream to downstream. Laterally, the plant biomass in the near-water zone was higher than in the far-water zone, while diversity demonstrated a reverse trend in the midstream. (4) The main environmental factors influencing plant distribution varied for different spatial dimensions. Longitudinally, the physical factor of soil is domination, particularly soil texture, which exhibits the strongest correlation with plant communities. Laterally, the chemical factor of soil is domination, such as soil organic matter and soil nitrate nitrogen content. This study enhances our understanding of the riparian area's ecology, and provides a scientific basis for plant cover restoration and ecological environment protection, and their management.

Keywords: riparian plant; species diversity; multidimensional spatial distribution; environmental factors; cluster analysis

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1. Introduction

The distributional characteristics of riverine riparian plant communities, as well as the biomass and diversity of those plants, have been the primary focus of research aimed at restoring riparian area ecosystems [1]. The stream's riparian area, commonly referred to as the riparian buffer zone, is the transitional zone between land and water along the river interface. This zone exhibits unique characteristics, dynamics, and edge effects, making it a critical source of terrestrial and aquatic species, and serving as an essential wildlife habitat. Moreover, the research has demonstrated that the community structure and succession of plants in riparian areas can significantly influence the heterogeneity of hydrological processes [2]. The plants that thrive in riparian areas play an additional distinct role in the landscape through serving as a transitional medium between terrestrial and aquatic ecosystems. Such plants exhibit specific ecological adaptations, and serve

as vital components for the overall functioning of the ecosystem [3]. At the same time, plants serve as a crucial component of the riparian area ecosystem, playing a vital role in safeguarding watershed stability, preventing water quality degradation, stabilizing the area, and preserving ecological diversity both within the riparian area and along the river [4,5]. The seasonal fluctuations in water levels within the riparian area led to variations in environmental factors such as light availability, water pressure, and oxygen levels. These fluctuations impose significant constraints on the growth, development, photosynthesis, and respiration of plants. Consequently, a series of changes occur in the distribution of plant communities within the zone, including alterations in distributional characteristics, species composition, species richness, abundance, coverage, and ecological functions [6]. From various perspectives, the riparian area's plants and soil play an indispensable role in regulating ecosystem processes. Therefore, studying the distributional characteristics of riparian plants and soil is highly significant for assessing the functionality of natural ecosystems and in facilitating the restoration of the riparian area plants.

The unique distributional characteristics of plant communities align with the gradient features of the surrounding environment, encompassing aspects such as species composition, species richness, dominant species types, biomass structure, and plant cover [7]. When evaluating the plant structures of riparian areas, plant diversity has served as a widely adopted quantitative measure by scholars in the field of plant ecology [8]. The differences in plant diversity across various plant communities may reflect their growth and adaptive characteristics, as plant diversity can be influenced by a variety of environmental factors that impact the distributional characteristics of these communities [9]. Furthermore, the distribution of biomass within a plant community significantly influences a range of ecological functions [7]. Despite the significance of these functions in ecological studies of riparian areas, only a limited number of studies have examined the biomass of major plant communities within riparian areas. Moreover, there are relatively few explorations of the relationship between soil properties and plants in riparian areas. Additionally, community biodiversity serves as a quantitative indicator of species composition, providing insights into the overall ecosystem structure. Since 1990, it has been suggested that prolonged water level inundation periods lead to reduced plant diversity, while fluctuating water levels contribute to a comparatively higher plant diversity [10]. Simultaneously, researchers have observed both positive and negative relationships between community biodiversity and soil properties. Consequently, further efforts are required to delve into the intricate relationships between plants and riparian area soils.

In recent years, several scholars have discovered that soil microorganisms play a crucial role in soil nutrient transformation and cycling processes. These microorganisms exhibit significant correlations with the diversity of plant communities in riparian areas, as well as the stability of riparian area ecosystems and their ecological functions [11]. Changes in the physical and chemical properties of soil play a significant role in enhancing soil nutrient availability, which in turn promotes the growth and development of plants [12]. Research has demonstrated that riparian area soils undergo changes corresponding to the fluctuations in water levels. The diversity of plants within the riparian area and variations in plant biomass can influence these changes. Alterations in soil moisture content can impact the structure of soil aggregates, subsequently leading to modifications in the physical and chemical properties of the soil [13]. Furthermore, studies have revealed that a decrease in soil moisture levels can result in a reduction in nutrients within the soil, subsequently influencing changes in plant cover [14]. Therefore, investigating changes in the distributional characteristics of plant communities and their relationship with soil physiochemistry under different inundation states in riparian areas can offer a solid theoretical foundation for assessing and restoring the overall health of wetland riparian areas.

2. Materials and Methods

2.1. Study Area

The Lingshan River is located in Quzhou City, Zhejiang Province, China. It lies between E119°1′41″~119°19′52″ and N28°44′10″~29°17′15″, situated in the Jinqu Basin within the western part of Zhejiang Province. The river originates from Shangling in Suichang County at an altitude of 1265 m, flows into Longyou County at the mouth of Mashukou in Mudu Township, and runs through the central part of Longyou County from the south to the north. Finally, it merges with the Qujiang River in Longyou County, serving as an important right-bank tributary at the upper reaches of the Qiantang River. The Lingshan River basin falls within the subtropical monsoon climate zone, characterized with abundant rainfall and distinct seasonal variations. The average annual temperature is 17.31 °C, with approximately 1966 h of sunshine and an average precipitation of 1.67 m. In 2008, the Muchen Reservoir was built in the upper reaches of the Lingshan River, with a catchment area of 397 km^2 and a total storage capacity of 125.71 million m^3. To meet domestic water, irrigation, landscape ecology, and hydropower requirements, 20 weirs were constructed from the Muchen reservoir to the confluence of the Qujiang River with the Lingshan River. The river basin area within Longyou County spans 367.62 km^2, with a mainstream length of 43.79 km and an average specific elevational drop of 2.45%. Overall, the Lingshan River represents a typical river in a hilly region.

2.2. Sample Collection and Laboratory Analysis

2.2.1. Vegetation Investigation

In April 2018, a riparian plant survey of Lingshan River was conducted through establishing monitoring sample plots. The river was divided into three reaches based on the channel gradient: upstream (S), midstream (Z), and downstream (X). In each section, 3~5 typical floodplains were selected according to the morphology, area, bending the degree and flow conditions. The locations of floodplains are shown in Figure 1 and Table 1. Meanwhile, in each floodplain, three lateral sections were set with 2–3 plant sample plots (1 m × 1 m) for each section at 5 m intervals. This selection process entailed avoiding low-lying areas, steep slopes, and locations significantly impacted by anthropogenic activities. A total of 120 sample plots were thus acquired.

Table 1. The sampling point section and monitoring point sample layout.

River Reach	Floodplain Name	Longitude	Latitude	Numbers of Plant Sample Plot
S1	Xikou Siqiao	119°09′53.68″	28°51′46.28″	8
S2	Jiangtan	119°09′41.26″	28°51′54.92″	6
S3	Xiaxuqiao	119°09′46.73″	28°53′18.95″	6
Z1	Sixia	119°09′33.95″	28°53′35.25″	5
Z2	Meicun	119°08′51.57″	28°53′48.08″	5
Z3	Zhoucun	119°08′00.62″	28°54′00.41″	6
X1	Jiangxiyan	119°10′32.99″	28°57′56.34″	6
X2	Sihou	119°10′29.33″	29°00′09.82″	6
X3	Shangyang	119°10′58.23″	29°03′00.46″	6
X4	Gaotie	119°10′28.31″	29°00′07.38″	9
X5	Caihongqiao	119°11′00.21″	29°03′06.41″	9

Each sample plot underwent scrutiny to document the species' nomenclature, abundance, height, and coverage of all herbaceous plants present. Following this documentation, all plants overground with each species were harvested according to their species and then were transported to the laboratory at −4 °C for biomass measurement. The plants that could not be accurately identified in the investigation were prepared and brought back to the laboratory. The identification of each plant species was conducted using references such as the Chinese Plant Image Library and the *Flora of China*.

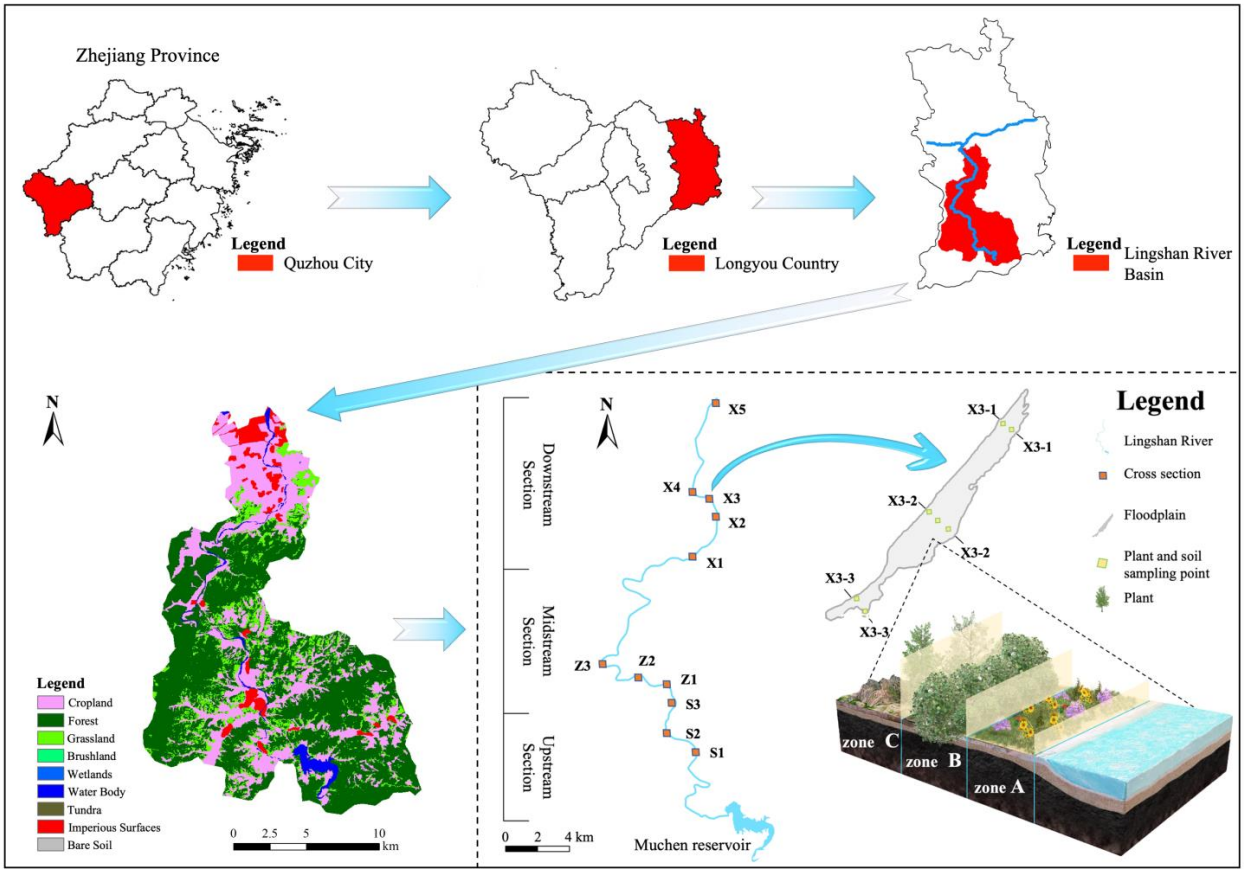


Figure 1. Map of the study area.

2.2.2. Soil and Water Factors Investigation

For each plant sample plot, the surface soil (0–20 cm) was collected using a five-point sampling method, thoroughly mixed, and transported back to the laboratory. The soil samples were measured for their physical and chemical properties, including soil saturated water holding capacity (SWHC), water content of soil (SCW), soil bulk density (BD), soil porosity (e), particle size distribution, pH, ammonia nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), total nitrogen (TN), soil organic matter (SOM), and total phosphorus (TP).

Additionally, along the edge of floodplains, the water depth (WD) of the river was determined using a steel ruler, and the river flow velocity (FL) was measured using an ultrasonic velocity meter at several points. The average value of each point is used to represent the depth of water and flow velocity characteristics of the floodplain.

2.2.3. Laboratory Analysis

In the laboratory, plant biomass samples were oven dried for 12 h at 105 °C and then oven dried for 72 h at 65 °C and weighed, which is the plant's dry biomass.

For soil samples, after removing roots and stones, one portion was stored in a refrigerator at 4 °C for the determination of ammonium nitrogen and nitrate nitrogen in the soil, and a second portion was sieved through different pore sizes (2 mm, 1 mm, and 0.15 mm) after drying naturally in a cool and ventilated location indoors. Then, thirteen soil physical-chemical properties were analyzed for the pretreated soil samples. SWHC and SWC was determined using the drying method (105 °C) [15]. The soil particle size and soil porosity were measured using a Bettersize2000 laser diffraction particle size analyzer from Dandong Baxter Instrument Co(Dandong, Liaoning Province, China). BD was determined via cutting ring. The pH of the soil was determined using the soil–water immersion method, with a soil/liquid ratio of 1:2.5. The mixture was stirred for one minute and was allowed to settle for 30 min before the measurement of the pH was conducted utilizing a pH meter.

NH_4^+-N and NO_3^--N contents were determined using the extraction–spectrophotometric method with potassium chloride [16]. SOM content was analyzed using the potassium dichromate heating method. TN content was determined using a Kjeldahl nitrogen tester. TP content was measured using an ultraviolet spectrophotometer from Nanjing Philips Instrument Co(Nanjing, Jiangsu, China). [17].

2.3. Parameters of Plant Characteristics

The parameters characterizing plant distribution include the biological composition, density, biomass, species diversity, and the values of the relative importance of communities.

(1) Relative importance value.

Considering that the Lingshan River is dominated by herbaceous plants, relative frequency and relative abundance were used as comprehensive quantitative indicators for evaluating the relative importance of species in the community [18].

$$IV = (Relative\ height + Relative\ cover)/2 \quad (1)$$

(2) The diversity indexes.

In order to determine the differences in the distributional characteristics of plant communities seen in different river reaches, the Patrick richness index (R), the Shannon–Wiener index (H), and the Pielou uniformity index (E) were selected to characterize community species diversity.

Patrick richness index (R):

$$R = S \quad (2)$$

Shannon–Wiener index (H):

$$H = -\sum_{i=1}^{s} P_i ln P_i \quad (3)$$

Pielou uniformity index (E):

$$E = H/\ln S \quad (4)$$

where S is the number of species recorded in quadrats, and Pi is the relative abundance of each species.

2.4. A method for Plant Community Classification Based on Cluster Analysis

Mathematical methods are typically employed in the quantitative classification of plants to analyze ecological quantitative relationships, yielding results that reveal specific ecological patterns [19]. Complete-linkage clustering, also known as farthest neighbor clustering, is a hierarchical clustering method commonly employed in data analysis. This method calculates the dissimilarity between clusters by considering the maximum pairwise dissimilarity between points in different clusters. Complete-linkage clustering aims to merge clusters that have the least similarity, thus emphasizing the most disparate elements when forming new clusters. One key advantage of complete-linkage clustering is its ability to detect compact, well-separated clusters in the data. So, this method can be sensitive to outliers and noise in the dataset due to its emphasis on maximum dissimilarity.

In this study, we conducted complete-linkage clustering analysis using the R language package, to classification of plant community in both longitudinal (classified by 11 floodplains) and lateral dimensions (classified by near-water area and far-water area), in which specifically focusing on dominant species with an importance value exceeding 5%.

2.5. Date Analysis

A one-way ANOVA was used as foundational assumptions for the parametric tests to analyze the species diversity indices of plant communities across various river reaches. The LSD analysis was conducted to assess the variability present in the dataset. ($p < 0.05$ statistically significant). The redundancy analysis (RDA) was selected to analyze the effect

of environmental factors on the differentiation characteristics of the plant community [20]. RDA was used Canoco5.0, plotted using Origin2021pro. A Pearson correlation was used to assess the associations between different soil factors, and the results were visualized using the R package "corrplot" [21].

3. Results

3.1. Plant Species and Life Form

On-site investigations revealed a total of 104 species belonging to 12 families and 92 genera of herbaceous plants. The dominant families were Poaceae, Compositae, Polygonaceae, Lamiaceae, Apiaceae, Cyperaceae, Brassicaceae, Caryophyllaceae, Scrophulariaceae, Crassulaceae, Rosaceae, Fabaceae, and Araceae. Among these, Poaceae accounted for 16.67%, and Compositae accounted for 9.65%. Polygonaceae, Lamiaceae, and Apiaceae each accounted for 5.26%; Cyperaceae, Brassicaceae, Caryophyllaceae, and Scrophulariaceae each accounted for 4.39%; Crassulaceae and Rosaceae each accounted for 3.51%; and Fabaceae and Araceae each accounted for 2.63%.

According to the characteristics of plant life forms, the plants were classified into the following four life types according to the *Flora of China*: annual herbs, accounting for 38.60%; perennial herbs, accounting for 52.63%; lianas, accounting for 2.63%; and woody plants, accounting for 6.14%. Additionally, among them, four families and four genera of ferns were also identified, namely *Microlepia marginata* (Houtt.) C. Chr., *Ceratopteris thalictroides* (L.) Brongn., *Marsilea quadrifolia* L., and *Humata repens* (L. f.) Diels.

3.2. Classification and Distribution of Vegetation Communities

From a longitudinal perspective, the plants of the 11 floodplains were clustered and analyzed using complete-linkage clustering (Figure 2a). The classification of plant communities was based on selecting level 4, which allowed the plants of the floodplain to be categorized into five distinct types. The communities were named based on the dominant species found within them.

(1) *Bidens pilosa* L.—*Centella asiatica* (L.) Urban community. This community contains 83 sample points, accounting for 17.8% of the total sample points. This group is commonly found and evenly distributed across the 11 floodplains in the upper, middle, and lower reaches of the river.

(2) *Cynodon dactylon* (L.) Pers.—*Conyza canadensis* (L.) Cronq. community. This community contains 185 sample points, accounting for 39.7% of the total sample points. The dominant species in this community is *Cynodon dactylon* (L.) Pers., and the companion species is *Salvia japonica* Thunb. This community is mainly distributed in the middle and lower reaches of the river, such as the Meicun floodplain (Z2), the Jiangxiyan floodplain (X1), and the Gaotieqiao floodplain (X4). It is commonly found in the near-water area.

(3) *Avena fatua* L.—*Inula japonica* Thunb.—*Clinopodium gracile* (Benth.) Matsum. community. This community contains 89 sample sites, accounting for 19.1% of the total sample sites. This community is widely distributed in eight floodplains, which are mostly located in the midstream of the river.

(4) *Cicuta virosa* L.—*Alternanthera philoxeroides* (Mart.) Griseb. community. This community contains 72 sample sites, accounting for 7.7% of the total sample sites. This community is distributed in ten floodplains, and most of the community is concentrated in the upstream of the river, such as the Xikousiqao floodplain (S1). The majority of the *Alternanthera philoxeroides* (Mart.) Griseb. is distributed in the near-water area of the floodplains.

(5) *Humulus scandens*—*Vicia sepium* L. community. This community contains 36 sample sites, accounting for 15.7% of the total sample sites. This community is relatively evenly distributed, and is common at both the near-water and far-water area, occurring at the Shangyang floodplain (X3), the Xiaxu floodplain (S3), the Meicun floodplain (Z3), and the Caihongqiao floodplain (X5).

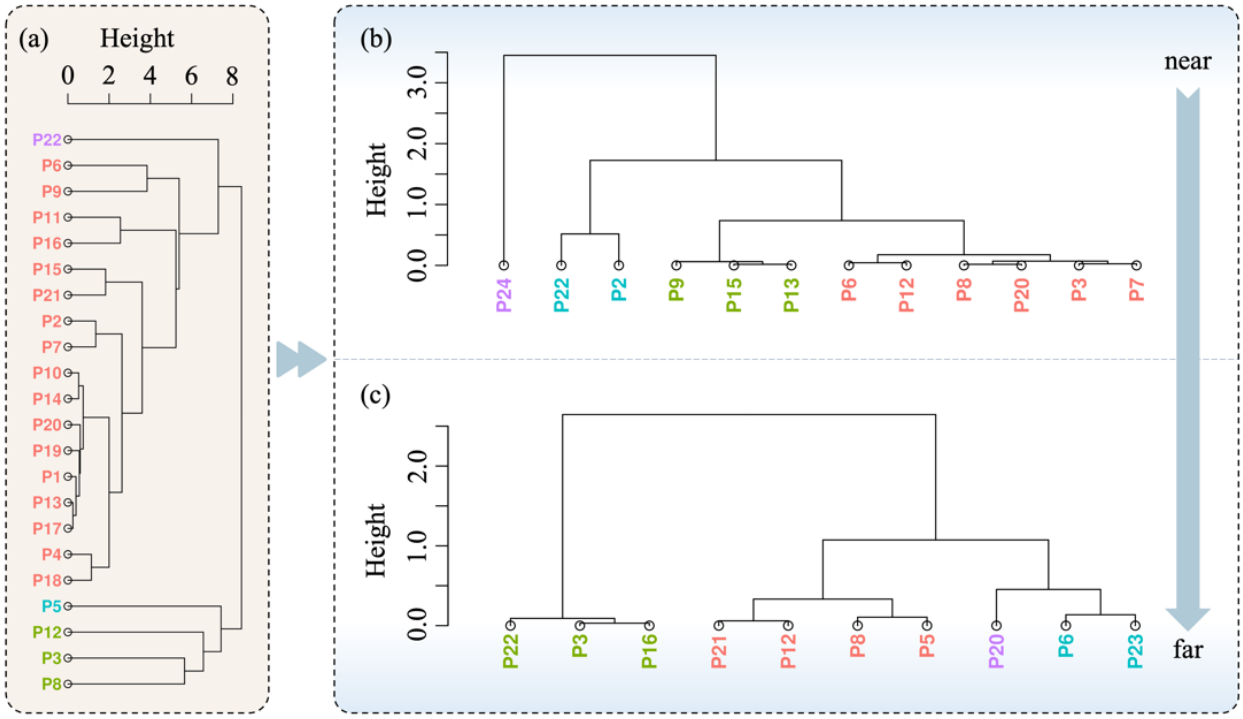


Figure 2. The results of plant community clustering under different spatial angles: (**a**) correlation of species with importance values greater than 5% in the floodplain and hierarchical cluster analysis; (**b**) cluster analysis of plant communities with importance values greater than 5% at 0 m distance from water; (**c**) cluster analysis of plant communities with importance values greater than 5% at a distance of 15 m from water. P1—*Poa annua* L.; P2—*Avena fatua* L.; P3—*Polypogon fugax* Nees ex Steud.; P4—*Imperata cylindrica* (L.) Beauv.; P5—*Cynodon dactylon* (L.) Pers.; P6—*Alopecurus aequalis* Sobol.; P7—*Inula japonica* Thunb.; P8—*Artemisia argyi* Levl. et Van.; P9—*Conyza canadensis* (L.) Cronq.; P10—*Gnaphalium affine* D. Don.; P11—*Bidens pilosa* L.; P12—*Polygonum lapathifolium* L.; P13—*Rumex acetosa* L.; P14—*Clinopodium gracile* (Benth.) Matsum.; P15—*Cicuta virosa* L.; P16—*Centella asiatica* (L.) Urban.; P17—*Cyperus iria* L.; P18—*Arenaria serpyllifolia* L.; P19—*Astragalus sinicus* L.; P20—*Vicia sepium* L.; P21—*Alternanthera philoxeroides* (Mart.) Griseb.; P22—*Humulus scandens*; P23—*Mariscus umbellatus* Vahl.; P24—*Marsilea quadrifolia* L.

From a lateral perspective, the plants in the near-water area were classified into four communities using complete-linkage clustering (Figure 2b). The analysis focused on species with importance values exceeding 5% in the 31 sample points located at 0 m from the water.

(1) *Polypogon fugax* Nees ex Steud.—*Alopecurus aequalis* Sobol.—*Artemisia argyi* Levl. et Van. community. This community contains 21 sample sites, accounting for 67.7% of the total number of sample sites. It is a dominant community in the near-water area.
(2) *Conyza canadensis* (L.) Cronq. community. This community includes 13 sample sites, or 41% of the total number of sample sites, with companion species of *Rumex acetosa* L. and *Cicuta virosa* L.
(3) *Humulus scandens*—*Avena fatua* L. community. This community comprises 10 sample sites, or 33% of the total number of sample sites, with no obvious companion species.
(4) *Marsilea quadrifolia* L. community. This community is a dominant species endemic to the near-water area, which contains three sample sites, or 10% of the total number of sites, with no obvious companion species.

The plants in the far-water area were classified into three clusters using complete-linkage clustering (Figure 2c). The analysis focused on species with importance values exceeding 5% in the 32 sample points located at a distance of 15 m from the water.

(1) *Humulus scandens*—*Polypogon fugax* Nees ex Steud. community. The community contains eight sites, representing 25% of the total sites, and the companion species are *Centella asiatica* (L.) Urban.
(2) *Artemisia argyi* Levl. et Van.—*Alternanthera philoxeroides* (Mart.) Griseb. community. This community contains 16 sample sites, representing 50% of the total sample sites. The companion species are *Polygonum lapathifolium* L. and *Cynodon dactylon* (L.) Pers. This community is the dominant community in the far-water zone.
(3) *Vicia sepium* L. community. This community contains eight sample sites, 25% of the total, with the companion species *Alopecurus aequalis Sobol.* and *Mariscus umbellatus Vahl*, which are the dominant plants endemic to the far water area.

3.3. Spatial Distribution of Plant Diversity, Richness and Biomass

3.3.1. Longitudinal Distribution of Plant Diversity, Richness and Biomass

The richness and diversity of plants in the Lingshan River floodplain land are illustrated in Figure 3. From a longitudinal perspective, the Shannon index of the plant communities on the floodplain ranged from 0.48 to 1.87, with Partrick index ranging from 3 to 12. The location of the floodplain within the river section and the distance from the water influenced the diversity of the plant community, as depicted in Figure 3. In the upstream section (S) the average number of species was 7.80, with a Shannon index of 1.31 and a Pielou index of 0.65. In the middle section (Z), the average number of species was 6.75, with a Shannon index of 1.20 and a Pielou index of 0.64. Conversely, in the downstream section (X), the average number of species of 5.82, with a Shannon index of 1.06 and a Pielou index of 0.63.

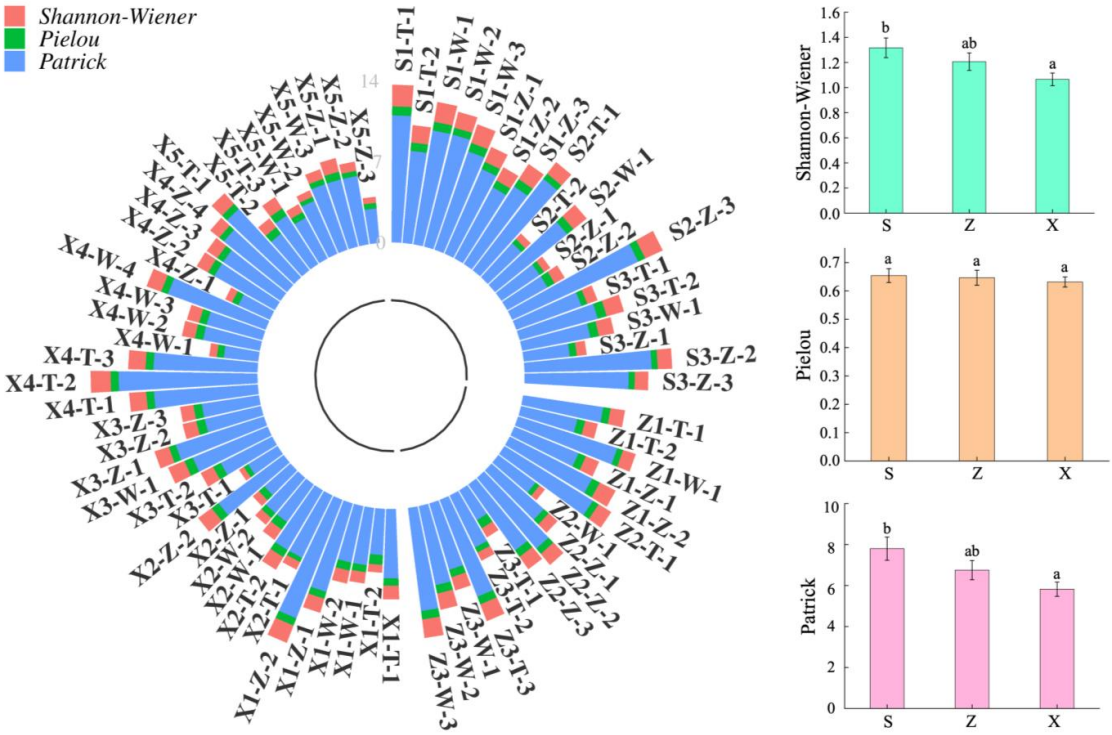


Figure 3. Spatial distribution and variability of species diversity of herbaceous plant communities on the Lingshan River floodplain. The first letters, S, Z, and X, represent the upstream, middle, and downstream of the river, respectively; the second letters, T, Z, and W, represent the different sections of each floodplain, which are the head section, middle section, and tail section (in the direction of the water); and the third numbers, 1/2/3, represent the distance of the sample from the water, which are 0 m and 15 m, respectively; "a" and "b" represents a significant difference between the two groups, and "ab" represents no significant difference.

Notably, the Pielou index showed a significant decreasing trend from upstream to downstream. Additionally, employing a one-way ANOVA revealed differences in the diversity index and the number of species at different reach, with significant disparities shown in the Patrick index and Shannon's diversity index ($p < 0.05$).

3.3.2. Lateral Distribution of Plant Diversity, Richness, and Biomass

At the lateral spatial scale, the richness, diversity indices, and biomass of the plants in the floodplain lands are presented in Table 2. In the near-water area, the dry biomass ranged from 82.91 to 1202.45 g/m^2, and the highest value was shown midstream (Z3 floodplain). The number of species varied from 4 to 9. Shannon's index ranged from 0.93 to 1.68, and the highest value was shown downstream (X2 floodplain). Pielou's index ranged from 0.56 to 0.75, and the highest value was shown midstream (Z3 floodplain).

Table 2. The diversity index and biomass in the different lateral area (0 m distance from water, 15 m distance from water).

	Cross-Section	Biomass (g/m^2)	Patrick	Shannon-Wiener	Pielou
Near-water	S1	268.98 ± 160.26	9.67 ± 1.53	1.68 ± 0.24	0.74 ± 0.06
	S2	351.02 ± 4.16	8.67 ± 4.16	1.19 ± 0.52	0.56 ± 0.11
	S3	204.97 ± 68.64	5.33 ± 1.15	1.05 ± 0.26	0.63 ± 0.11
	Z1	159.11 ± 88.48	8.03 ± 1.05	1.47 ± 0.53	0.64 ± 0.11
	Z2	257.35 ± 234.69	6.33 ± 2.52	0.96 ± 0.13	0.52 ± 0.09
	Z3	1202.45 ± 1582.95	4.51 ± 2.12	1.06 ± 0.21	0.75 ± 0.11
	X1	82.91 ± 41.39	6.33 ± 1.53	1.15 ± 0.15	0.63 ± 0.03
	X2	252.08 ± 180.52	4.33 ± 1.53	1.57 ± 0.53	0.61 ± 0.19
	X3	379.99 ± 132.75	6.03 ± 2.65	1.67 ± 0.53	0.62 ± 0.17
	X4	267.34 ± 256.32	5.06 ± 3.46	0.93 ± 0.47	0.62 ± 0.04
	X5	263.59 ± 81.5	6.03 ± 2.14	1.08 ± 0.26	0.61 ± 0.06
Far-water	S1	181.07 ± 120.14	8.33 ± 1.53	1.41 ± 0.11	0.67 ± 0.05
	S2	165.11 ± 43.09	5.33 ± 2.31	1.04 ± 0.41	0.63 ± 0.14
	S3	116.33 ± 68.12	9.03 ± 2.83	1.41 ± 0.21	0.66 ± 0.19
	Z1	82.53 ± 25.21	5.52 ± 0.71	1.18 ± 0.08	0.66 ± 0.05
	Z2	70.11 ± 17.73	6.52 ± 2.12	1.02 ± 0.32	0.61 ± 0.12
	Z3	70.91 ± 16.62	6.13 ± 1.41	1.12 ± 0.45	0.62 ± 0.17
	X1	136.57 ± 142.85	6.67 ± 3.79	1.15 ± 0.46	0.75 ± 0.09
	X2	159.05 ± 58.83	5.67 ± 1.53	1.16 ± 0.36	0.67 ± 0.1
	X3	230.63 ± 6.12	5.02 ± 0.02	1.21 ± 0.02	0.75 ± 0.01
	X4	90.33 ± 16.33	7.67 ± 3.79	1.33 ± 0.34	0.68 ± 0.05
	X5	146.68 ± 92.08	5.02 ± 1.03	0.81 ± 0.18	0.51 ± 0.17

In far-water area, the biomass ranged from 70.11 to 230.63 g/m^2, the highest value was showed in downstream (X3 floodplain). The number of species ranging from 5 to 9. The Shannon's index ranged from 0.81 to 1.41, and Pielou's evenness index from 0.52 to 0.74.

Compare the two areas, Shannon's index and Pielou's index the Patrick abundance indexes of the far-water area in the middle reaches exhibited higher than that in the near-water area mostly. Furthermore, most of the far-water area of the floodplains displayed higher values for compared to the near-water area of the floodplains. In total, the Shannon-wiener index exhibited a substantial difference of 2.27 between the near and far sections, indicating higher diversity in the far section. Conversely, the difference between the mean values of the indices for each river reach was used to represent the differences. The Pielou index showed a slight difference of 0.03,the Patrick index showed a slight difference of 0.05, suggesting similar evenness between the near and far sections. The Biomass values were significantly higher compared to the far section, with a difference of 203.67.

3.4. Identification of Key Environmental Factors

(1) Screening of the main physical drivers of plant communities

The two principal axes collectively account for 27.85% of the variation observed in the plant communities (Figure 4). Along the first taxonomic axis, each species showed obvious

selectivity for soil factors. Axis 1 represents the soil texture of the floodplain of the river, with most communities distributed in the first two quadrants. This observation suggests that there is a high correlation between each plant community and soil moisture content, soil texture, and water flow rate. Most soil chemical properties showed different levels between the two habitats (Figure 5).

The first five communities are longitudinally distributed, with communities *VI* to *VIII* representing the plants in near-water area. Communities *X* to *XII* represent plant communities located at the far-water area. In the longitudinal distribution, communities *IV* exhibit stronger correlations with soil texture (Figure 5). Communities *I*, *II*, and *III* display weaker correlations with physical environmental factors when contrasted with communities *IV*. This could be attributed to the presence of plants within community *IV*, which possesses strong selective properties. In the lateral distribution, community *VI* in the near-water area shows a positive correlation with BD (Figure 5). There was no strong correlation between the plant communities between the far-water area and the physical factors.

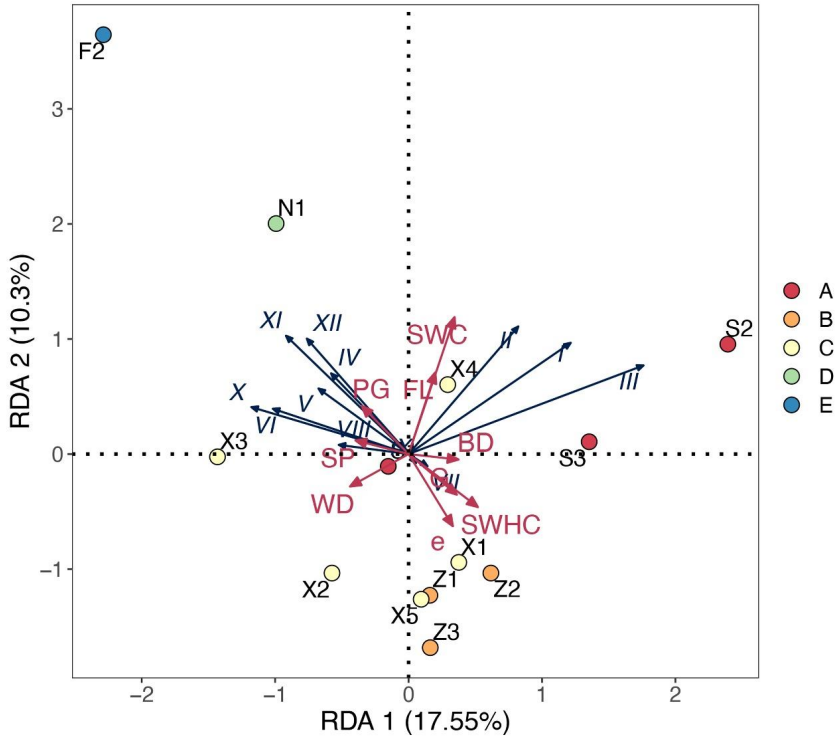


Figure 4. An illustration of the RDA analysis of plant communities in relation to physical environmental factors. WD—water depth; BD—bulk density; e—porosity; SWHC—saturated water holding capacity; SWC—soil moisture content; FL—flow rate; SP—clay; PG—silt; G—sand; A—upstream; B—midstream; C—downstream; D—near-water zone; E—far-water zone.

(2) Screening of the main chemical drivers of each plant community

The two principal axes collectively account for 24.27% of the variation observed in the plant communities (Figure 6). Notably, among the chemical and environmental factors, the correlations between soil nitrate nitrogen and soil pH with axis 1 were the strongest.

The first five communities are longitudinally distributed, with communities *VI* to *VIII* representing the plants in near-water area. Communities *X* to *XII* represent plant communities located at far-water area. In the longitudinal distribution, communities *I*—*III* demonstrate positive correlations with soil pH and TP, while community *IV* displays a positive correlation with TN and NH_4^+-N (Figure 7). In the lateral distribution, communities *VI* in near-water area shows a positive correlation with SOM (Figure 5). Notably, the three

plant communities located in the far-water area exhibit a strong positive correlation with NO_3^--N.

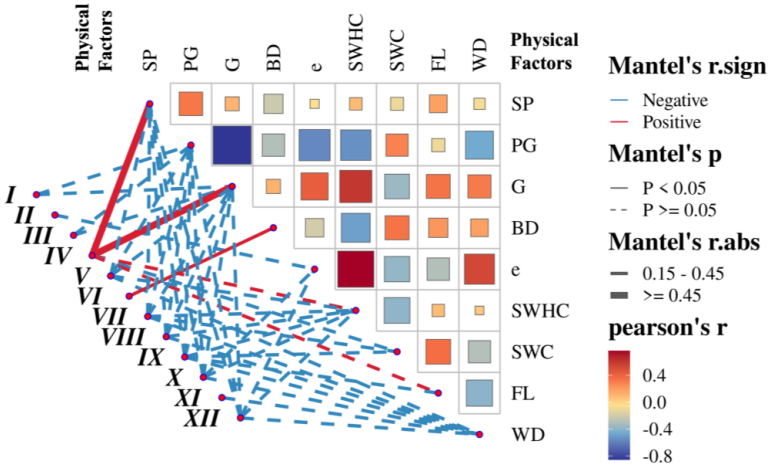


Figure 5. The correlation of each plant community with physical environmental factors. *I*—*Bidens pilosa* L.—*Centella asiatica* (L.) urban community; *II*—*Cynodon dactylon* (L.) Pers.—*Conyza canadensis* (L.) Cronq. community; *III*—*Avena fatua* L.—*Inula japonica* Thunb.—*Clinopodium gracile* (Benth.) Matsum. community; *IV*—*Cicuta virosa* L.—*Alternanthera philoxeroides* (Mart.) Griseb. community; *V*—*Humulus scandens*—*Vicia sepium* L. community; *VI*—*Polypogon fugaxi* Nees ex Steud.—*Alopecurus aequalis Sobol.*—*Artemisia argyi* Levl. et Van. community; *VII*—*Conyza canadensis* (L.) Cronq. community; *VIII*—*Humulus scandens*—*Avena fatua* L. community; *IX*—*Marsilea quadrifolia* L. community; *X*—*Humulus scandens*—*Polypogon fugax* Nees ex Steud. community; *XI*—*Artemisia argyi* Levl. et Van.—*Alternanthera philoxeroides* (Mart.) Griseb. community; *XII*—*Vicia sepium* L. community. WD—water depth; BD—bulk density; e—porosity; SWHC—saturated water holding capacity; SWC—soil moisture content; FL—flow rate; SP—clay; PG—silt; G—sand.

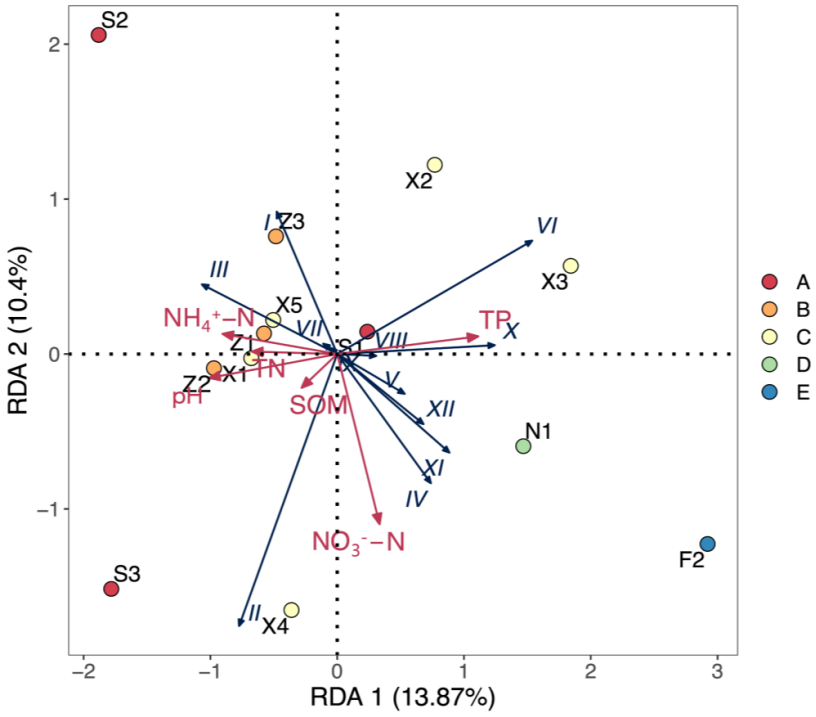


Figure 6. The RDA analysis of plant communities in relation to chemical environmental factors: TN—total nitrogen content; TP—total phosphorus concentration; NO_3^--N—nitrate nitrogen; SOM—organic matter; NH_4^+-N—ammonia nitrogen; A—upstream; B—midstream; C—downstream; D—near-water zone; E—far-water zone.

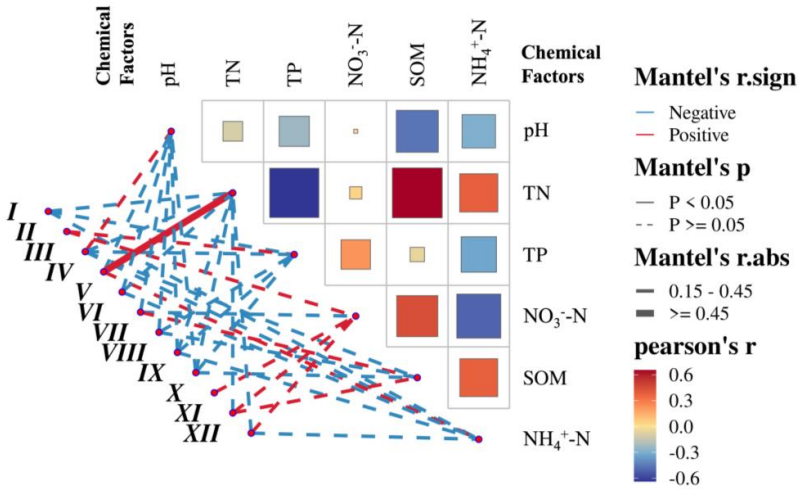


Figure 7. The correlation of each plant community with chemical environmental factors. *I*—*Bidens pilosa* L.—*Centella asiatica* (L.) urban community; *II*—*Cynodon dactylon* (L.) Pers.—*Conyza canadensis* (L.) Cronq. community; *III*—*Avena fatua* L.—*Inula japonica* Thunb.—*Clinopodium gracile* (Benth.) Matsum. community; *IV*—*Cicuta virosa* L.—*Alternanthera philoxeroides* (Mart.) Griseb. community; *V*—*Humulus scandens*—*Vicia sepium* L. community; *VI*—*Polypogon fugaxi* Nees ex Steud.—*Alopecurus aequalis* Sobol.—*Artemisia argyi* Levl. et Van. community; *VII*—*Conyza canadensis* (L.) Cronq. community; *VIII*—*Humulus scandens*—*Avena fatua* L. community; *IX*—*Marsilea quadrifolia* L. community; *X*—*Humulus scandens*—*Polypogon fugax* Nees ex Steud. community; *XI*—*Artemisia argyi* Levl. et Van.—*Alternanthera philoxeroides* (Mart.) Griseb. community; *XII*—*Vicia sepium* L. community. TN—total nitrogen content; TP—total phosphorus concentration; NO_3^--N nitrate nitrogen; SOM—organic matter; NH_4^+-N—ammonia nitrogen.

4. Discussion

The species composition, community structure, and spatial distribution of plant communities in the riparian of the river differ significantly from the adjacent terrestrial and aquatic plant communities [22,23]. The riparian area is characterized by alternating periods of dryness and wetness, resulting in cyclic changes in water levels [24]. This cyclic inundation environment has led to the formation of numerous secondary areas of bare ground. Plant growth and reproduction in the riparian area are closely associated with the unique environment. Moreover, there is a discernible pattern of change in the structural characteristics within the plant community along the environmental gradient. Notably, the soil particle size structure is considered to be one of the key factors influencing the distributional patterns of plant community traits [25,26]. Therefore, the distribution of plants is significantly influenced by the soil texture, which in turn affects the availability of nutrient elements and hydrological properties. It is important to note that the physical structure of the soil plays a critical role in its ecological functioning and its ability to provide sustainable ecosystem services [27,28]. The findings of this study reveal that the species composition in the riparian area of the Lingshan River is predominantly composed of one-year or two-year herbaceous plants, with Poaceae being the dominant families. Herbaceous plants exhibit a robust ability to survive and adapt to diverse environments. Additionally, they possess well-developed root systems, enabling efficient nutrient and water absorption, thereby enhancing their adaptation to natural river channels. Notably, compositae demonstrate a shorter growth cycle, enabling them to thrive in harsh environments. Furthermore, they exhibit a relatively rapid reproduction and growth mode, allowing them to better adapt to various natural environments [29–31]. In the study area, the one-year and two-year herbaceous plants collectively comprised 91.23% of all plant species, making them the dominant plant type in the area. The rapid growth and development of these types of plants can be attributed to their ability to quickly adapt to environmental changes. The riparian area, characterized by alternating wet and dry conditions, contributes to the prevalence of

the two-year herbaceous plants as the dominant plant type [32,33]. Existing research has demonstrated that the prevalence of annual species in wet and dry areas is attributed to their ability to rapidly establish roots and reproduce within the relatively short period when the shoreland becomes exposed, illustrating why the herb is the dominant life type [34].

The plant community diversity index measures both the species richness and the evenness of species distribution across a given region [35]. The plant communities in the riparian area are influenced by the proximity of the river and various environmental factors [34]. In this study, the Patrick index and the Shannon–Wiener diversity index of the plant community in the river floodplain exhibited a decreasing trend from upstream to downstream. Additionally, there was a transition from sandy loamy soil in the upstream to loamy soil in the downstream, characterized by an increase in clay particle content and a decrease in sand particle content. In the upstream area, the higher diversity of plant species and plants may be attributed to the higher sand particle content, which leads to increased porosity, enabling better air contact for plant growth, hence facilitating faster growth [36]. Furthermore, this study revealed significant differences ($p < 0.05$) in the number of species and the Shannon–Wiener diversity index among different reaches of the river. These variations can be attributed to distinct hydrological conditions, soil texture, and nutrient element profiles observed from upstream to downstream within the riparian areas. Additionally, according to the map of the study area in Figure 2, the upstream land type is mostly forested, while the downstream land type is mostly cultivated land. Therefore, humans have modified the riparian areas according to their respective needs, which has also contributed to the significant differences between the sample plots.

A complete linkage clustering was used to assess plant species from different spatial perspectives and perform a longitudinal and lateral delineation of the plant communities. Among the various river-rich plant types, the *Cynodon dactylon* (L.) Pers. community emerged as the dominant species [37]. The plants in the study area were characterized by a low number of species, a simple community composition, and a predominance of herbaceous plants. The reason for the dominance of *Cynodon dactylon* (L.) Pers. in this area may be due to its well-developed root system and contemporaneous tissues, which ensure sufficient nutrient and energy reserves after being removed from the water environment through the acceleration of the root system's growth and the distribution mechanism of the below-ground biomass under adverse conditions [37,38]. Furthermore, this study revealed that the majority of plant communities were concentrated in the upstream and midstream. This distributional pattern may be attributed to the comparatively lower levels of anthropogenic interference here, as well as the more stable natural conditions present in the upstream and midstream of the Lingshan River reach. In contrast, the down-stream experienced greater anthropogenic disturbances, leading to the slower and less stable growth of the plant communities.

A comparison of the plant communities based on distance to water shows that the dominant communities in the near-water area are the *Polypogon fugax* Nees ex Steud.—*Alopecurus aequalis* Sobol.—*Artemisia argyi* Levl. et Van. community, and an endemic plant community, the *Marsilea quadrifolia* L. community. Meanwhile, the dominant plant community in the far-water zone is the *Humulus scandens*—*Polypogon fugax* Nees ex Steud. community. *Humulus scandens* is China's native plant, and is therefore more widely distributed. Studies have shown that *Humulus scandens* is more tolerant of drought, and as a native plant, growth is more advantageous, so the distance from the water has little effect on the plant [39]. These existing plant communities have undergone long-term natural selection; however, plant community construction is a long-term process, and long-term positional monitoring is also needed to extensively reveal the coupling relationship between the distribution of natural plant communities and environmental factors [40].

Riparian area soils have special functional, textural, and nutrient characteristics [41]. Riparian area plants play an important role in maintaining the stability of river ecosystems, and plant community diversity is one of the most important indicators of the stability and complexity of the plant community [42]. Finding the environmental factors that drive

their development is important for understanding the requirements for the restoration and stabilization of riparian area ecosystems. The soil in riparian areas is not only affected by plant root growth, but also by the hydrological characteristics of the river. For example, floodplain hydrological conditions significantly affect plant community distribution [43]. It has also been shown that plant growth and biodiversity are inextricably linked to soil conditions, which significantly affect biomass allocation and species diversity in plant communities [44]. Some studies have shown that there is a strong correlation between soil carbon and nitrogen content and plant growth and development, which is somewhat similar to the conclusions reached in this study [45]. At the same time, studies have also shown that nitrogen is one of the elements required in large quantities for plant growth and development and is a key element in the adjustment of ecosystems [44,46]. This is more in line with the findings of this study, which identified that nitrate–nitrogen content is significantly correlated with species development. Soil organic matter promotes the formation of soil structure, raises the temperature of the soil, promotes the growth and development of crops, and improves the soil's fertilizer retention capacity and buffering properties [47]. However, it is worth mentioning that some correlation exists between these two factors, as both are related to soil chemical properties. Furthermore, previous studies have demonstrated significant correlations between soil organic nitrogen content and acidity/alkalinity with climatic factors such as temperature and rainfall [48]. Additionally, from Figure 7, it is evident that 40% of the twelve plant communities exhibit a strong positive correlation with soil nitrate nitrogen. This finding suggests that disturbance factors associated with soil chemical properties play a prominent role in shaping the structure of plant communities in the riparian area. It has been shown that there is a strong positive correlation between soil organic matter and plant growth and development, which is consistent with the findings of this study that typical species have strong positive correlations with soil organic matter [49]. Moreover, the spatial arrangement of each plant community in the sorting space offers valuable insights into their ecological traits. Through the analysis of their spatial distribution and correlation with environmental factors, we can enhance our understanding of the ecological dynamics and interactions in the riparian ecosystem.

A comparison of the distribution of plant communities from different spatial perspectives shows that the plant communities divided longitudinally are more affected by physical environmental factors, soil physical properties, and mechanical composition; meanwhile, the plant communities divided according to the lateral distance from water have a higher correlation with soil chemical factors, and in particular, the nitrate nitrogen content, pH value, and soil water content affect the distribution of plant communities in the far-water zones. It has been shown that changes in soil moisture can lead to changes in soil physic-chemical properties such as soil structure (aggregates) and organic matter content [29]. Therefore, in arid areas, soil water content becomes the main environmental factor limiting the growth of plants, which is consistent with the conclusion of this paper. At the same time, soil physical and chemical properties, including soil water content, pH, organic matter, etc., have a certain impact on the species composition and plant diversity of riparian area plant communities. Specifically, soil pH in the riparian area promotes the decomposition rate of soil enzymes [50]. The present study also found that the pH level had a more significant effect on the distribution of plants because it can indirectly increase the species richness and diversity of plant communities through enhancing the soil fertility.

In summary, in this study, the most influential factor on the diversity of plant species in the Lingshan River floodplain is soil texture, which, as a comprehensive environmental factor, is subject to significant changes in hydrological conditions, soil chemical properties, temperature, light, and flooding time. Simultaneously, as depicted in Figure 2 illustrating the land use types, it is evident that human activities, including agricultural practices and urbanization, are exerting influences on the soil texture, resulting in alterations within both the upstream and downstream regions of the Lingshan River. These anthropogenic

interventions have positioned the soil texture of the river basin as a pivotal factor impacting the vegetation dynamics.

5. Conclusions

(1) The main conclusions of this study are as follows. In the survey of floodplain plants in the riparian zone of the Lingshan River, a total of 104 species belonging to 12 families were recorded, in which Poaceae (16.67%) and Compositae (9.65%) showed significant dominance.

(2) In the plant community delineation based on the complete linkage clustering, five plant communities were classified along the longitudinal scale of the river, four plant communities were in the near-water zone, and three plant communities were in the far-water zone. The Lingshan River riparian area is similarly spatially differentiated, with the dominant community in the longitudinal space being the *Cynodon dactylon* (L.) Pers.—*Conyza canadensis* (L.) Cronq. community. The dominant community in the near-water zone (0 m from water) in the lateral space is the *Artemisia argyi* Levl. et Van.—*Alternanthera philoxeroides* (Mart.) Griseb. community, and also an endemic plant community—the *Marsilea quadrifolia* L. community. The dominant community in the far-water zone (15 m from the water) is the *Artemisia argyi* Levl. et Van.—*Alternanthera philoxeroides* (Mart.) Griseb. community.

(3) Under conditions of natural water level variation, the plant diversity and community distribution in the riparian area of the Lingshan River are highly differentiated in each space. From a longitudinal spatial point of view, the diversity of species and the number of species are significantly differentiated, and the diversity index from the upstream to the downstream shows a significant decrease. When analyzed from the lateral point of view, the biomass of the near-water zone is generally higher than that of the far-water zone when compared with that of the zone at a distance of 15 m from the water. However, the diversity of species shows a reversed trend.

(4) The environmental factors affecting the distribution of plants varied under different spatial influences, and this study showed that plant communities in the longitudinal space were mainly correlated with soil physical factors and had the highest degree of response to soil texture. Meanwhile, the plant communities in the lateral space had a high correlation with soil chemical factors, of which the dominant ones were soil organic matter and soil nitrate nitrogen content.

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References

1. Moura Júnior, 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]
2. Baniya, M.B.; Asaeda, T.; Fujino, T.; Jayasanka, S.M.D.H.; Muhetaer, G.; Li, J. Mechanism of Riparian Vegetation Growth and Sediment Transport Interaction in Floodplain: A Dynamic Riparian Vegetation Model (DRIPVEM) Approach. *Water* **2019**, *12*, 77. [CrossRef]
3. Gundersen, P.; Laurén, A.; Finér, L.; Ring, E.; Koivusalo, H.; Sætersdal, M.; Weslien, J.-O.; Sigurdsson, B.D.; Högbom, L.; Laine, J.; et al. Environmental Services Provided from Riparian Forests in the Nordic Countries. *Ambio* **2010**, *39*, 555–566. [CrossRef] [PubMed]
4. Sakano, H. Effects of Vegetation in the Littoral Zone on the Reduction of Predation Pressure by Largemouth Bass Micropterus Salmoides. *Nippon. Suisan Gakkaishi* **2012**, *78*, 988–990. [CrossRef]
5. 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]
6. Xu, C.; Xu, Z.; Yang, Z. Reservoir Operation Optimization for Balancing Hydropower Generation and Biodiversity Conservation in a Downstream Wetland. *J. Clean. Prod.* **2020**, *245*, 118885. [CrossRef]
7. Dwire, K.A.; Kauffman, J.B.; Brookshire, E.N.J.; Baham, J.E. Plant Biomass and Species Composition along an Environmental Gradient in Montane Riparian Meadows. *Oecologia* **2004**, *139*, 309–317. [CrossRef] [PubMed]
8. Westoby, M.; Falster, D.S.; Moles, A.T.; Vesk, P.A.; Wright, I.J. Plant Ecological Strategies: Some Leading Dimensions of Variation Between Species. *Annu. Rev. Ecol. Syst.* **2002**, *33*, 125–159. [CrossRef]
9. 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. [CrossRef]
10. Rapport, D.J. Evolution of Indicators of Ecosystem Health. In *Ecological Indicators*; McKenzie, D.H., Hyatt, D.E., McDonald, V.J., Eds.; Springer: Boston, MA, USA, 1992; pp. 121–134.
11. Greenway, M.; Jenkins, G.; Polson, C. Macrophyte Zonation in Stormwater Wetlands: Getting It Right! A Case Study from Subtropical Australia. *Water Sci. Technol.* **2007**, *56*, 223–231. [CrossRef]
12. Martin, C.; Pohl, M.; Alewell, C.; Körner, C.; Rixen, C. Interrill Erosion at Disturbed Alpine Sites: Effects of Plant Functional Diversity and Vegetation Cover. *Basic Appl. Ecol.* **2010**, *11*, 619–626. [CrossRef]
13. Nóbrega, J.S.; Gomes, V.R.; de Lima, G.S.; Torres, R.A.F. Hydrogen Peroxide Alleviates Salt Stress Effects on Gas Exchange, Growth, and Production of Naturally Colored Cotton. *Plants* **2024**, *13*, 390. [CrossRef] [PubMed]
14. Vergne, D.D.C.; Rosalem, L.M.P.; Wendland, E.C.; Anache, J.A.A.; Martins Da Silva, M.C.; Boschi, R.S.; Silva Matos, D.M.D. Experimental Study on Potential Influence of the Invasive Hedychium Coronarium J. König on the Evapotranspiration of Riparian Plant Community. *Plants* **2023**, *12*, 1746. [CrossRef] [PubMed]
15. Johnson, S.W. Agricultural Chemistry-Soil Analysis; Notice of the Agricultural Chemistry of the Geological Surveys of Kentucky and Arkansas. *Am. J. Sci.* **1861**, *s2-32*, 233–252. [CrossRef]
16. 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. [CrossRef]
17. Skuodienė, R.; Matyžiūtė, V.; Šiaudinis, G. Soil Seed Banks and Their Relation to Soil Properties in Hilly Landscapes. *Plants* **2023**, *13*, 104. [CrossRef] [PubMed]
18. Su, X.; Bejarano, M.D.; Yi, X.; Lin, F.; Ayi, Q.; Zeng, B. Unnatural Flooding Alters the Functional Diversity of Riparian Vegetation of the Three Gorges Reservoir. *Freshw. Biol.* **2020**, *65*, 1585–1595. [CrossRef]
19. Kulhánek, M.; Asrade, D.A.; Suran, P.; Sedlář, O.; Černý, J.; Balík, J. Plant Nutrition—New Methods Based on the Lessons of History: A Review. *Plants* **2023**, *12*, 4150. [CrossRef] [PubMed]
20. Wendroth, O. Multivariate Analysis of Ecological Data Using CANOCO. *Vadose Zone J.* **2004**, *3*, 1057. [CrossRef]
21. Wei, T.; Simko, V.; Levy, M.; Xie, Y.; Jin, Y.; Zemla, J.; Freidank, M.; Cai, J.; Protivinsky, T. Corrplot: Visualization of a Correlation Matrix. 2021. Available online: https://cran.r-project.org/web/packages/corrplot/corrplot.pdf (accessed on 17 July 2022).
22. Abdel Latef, A.A.; Tran, L.-S.P. Impacts of Priming with Silicon on the Growth and Tolerance of Maize Plants to Alkaline Stress. *Front. Plant Sci.* **2016**, *7*, 243. [CrossRef]
23. Ye, C.; Cheng, X.; Liu, W.; Zhang, Q. Revegetation Impacts Soil Nitrogen Dynamics in the Water Level Fluctuation Zone of the Three Gorges Reservoir, China. *Sci. Total Environ.* **2015**, *517*, 76–85. [CrossRef] [PubMed]
24. Sun, X.; Zhou, Q.; Ren, W.; Li, X.; Ren, L. Spatial and Temporal Distribution of Acetochlor in Sediments and Riparian Soils of the Songhua River Basin in Northeastern China. *J. Environ. Sci.* **2011**, *23*, 1684–1690. [CrossRef]
25. Tilman, D.; Reich, P.B.; Knops, J.M.H. Biodiversity and Ecosystem Stability in a Decade-Long Grassland Experiment. *Nature* **2006**, *441*, 629–632. [CrossRef]

26. Ives, A.R.; Carpenter, S.R. Stability and Diversity of Ecosystems. *Science* **2007**, *317*, 58–62. [CrossRef]
27. Amundson, R.; Berhe, A.A.; Hopmans, J.W.; Olson, C.; Sztein, A.E.; Sparks, D.L. Soil and Human Security in the 21st Century. *Science* **2015**, *348*, 1261071. [CrossRef] [PubMed]
28. Keesstra, S.D.; Bouma, J.; Wallinga, J.; Tittonell, P.; Smith, P.; Cerdà, A.; Montanarella, L.; Quinton, J.N.; Pachepsky, Y.; van der Putten, W.H.; et al. The Significance of Soils and Soil Science towards Realization of the United Nations Sustainable Development Goals. *Soil* **2016**, *2*, 111–128. [CrossRef]
29. Bravo-Garza, M.R.; Bryan, R.B.; Voroney, P. Influence of Wetting and Drying Cycles and Maize Residue Addition on the Formation of Water Stable Aggregates in Vertisols. *Geoderma* **2009**, *151*, 150–156. [CrossRef]
30. Catford, J.A.; Morris, W.K.; Vesk, P.A.; Gippel, C.J.; Downes, B.J. Species and Environmental Characteristics Point to Flow Regulation and Drought as Drivers of Riparian Plant Invasion. *Divers. Distrib.* **2014**, *20*, 1084–1096. [CrossRef]
31. Franklin, H.M.; Carroll, A.R.; Chen, C.; Maxwell, P.; Burford, M.A. Plant Source and Soil Interact to Determine Characteristics of Dissolved Organic Matter Leached into Waterways from Riparian Leaf Litter. *Sci. Total Environ.* **2020**, *703*, 134530. [CrossRef]
32. Jayasuriya, M.T.; Stella, J.C.; Germain, R.H. Can Understory Plant Composition and Richness Help Designate Riparian Management Zones in Mesic Headwater Forests of the Northeastern United States? *J. For.* **2021**, *119*, 574–588. [CrossRef]
33. Koirala, S.; Jung, M.; Reichstein, M.; De Graaf, I.E.M.; Camps-Valls, G.; Ichii, K.; Papale, D.; Ráduly, B.; Schwalm, C.R.; Tramontana, G.; et al. Global Distribution of Groundwater-vegetation Spatial Covariation. *Geophys. Res. Lett.* **2017**, *44*, 4134–4142. [CrossRef]
34. Lomolino, M.V. Elevation Gradients of Species-Density: Historical and Prospective Views. *Glob. Ecol. Biogeogr.* **2001**, *10*, 3–13. [CrossRef]
35. Cadotte, M.W.; Carscadden, K.; Mirotchnick, N. Beyond Species: Functional Diversity and the Maintenance of Ecological Processes and Services: Functional Diversity in Ecology and Conservation. *J. Appl. Ecol.* **2011**, *48*, 1079–1087. [CrossRef]
36. Ma, Y.; Chen, F.; Chen, S.; Guan, S.; Chen, C. Effects of Reverse Seasonal Submersion on the Germination and Persistence of Soil Seed Banks in Hydro-fluctuation Belts. *Ecohydrology* **2018**, *11*, e2008. [CrossRef]
37. Sabo, J.L.; Sponseller, R.; Dixon, M.; Gade, K.; Harms, T.; Heffernan, J.; Jani, A.; Katz, G.; Soykan, C.; Watts, J.; et al. Riparian zones increase regional species richness by harboring different, not more, species. *Ecology* **2005**, *86*, 56–62. [CrossRef]
38. Zhang, B.; Guo, J.-S.; Fang, F.; Li, Z.; Fu, C. Concentration of Nutrients in the Soil in Water-Level-Fluctuating Zone of Three Gorges Reservoir. *Ecohydrol. Hydrobiol.* **2012**, *12*, 105–114. [CrossRef]
39. Anderson, B.G.; Rutherfurd, I.D.; Western, A.W. An Analysis of the Influence of Riparian Vegetation on the Propagation of Flood Waves. *Environ. Model. Softw.* **2006**, *21*, 1290–1296. [CrossRef]
40. Ye, C.; Chen, C.; Du, M.; Liu, W.; Zhang, Q. Revegetation Affects Soil Denitrifying Communities in a Riparian Ecotone. *Ecol. Eng.* **2017**, *103*, 256–263. [CrossRef]
41. Fukami, T.; Nakajima, M. Complex Plant–Soil Interactions Enhance Plant Species Diversity by Delaying Community Convergence. *J. Ecol.* **2013**, *101*, 316–324. [CrossRef]
42. Dou, C.; Xia, J.; Cai, W.; Zeng, Z.; Liu, X.; Li, J.; Zu, J.; Liu, Z.; Wang, Y. Phosphorus Spatial Variation and Environmental Buffering Capacity of Mountainous River Bars. *Water. Air. Soil Pollut.* **2023**, *234*, 214. [CrossRef]
43. 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]
44. Brown, P.H.; Zhao, F.-J.; Dobermann, A. What Is a Plant Nutrient? Changing Definitions to Advance Science and Innovation in Plant Nutrition. *Plant Soil* **2022**, *476*, 11–23. [CrossRef]
45. Lv, P.; Sun, S.; Medina-Roldánd, E.; Zhao, S.; Hu, Y.; Guo, A.; Zuo, X. Effects of Habitat Types on the Dynamic Changes in Allocation in Carbon and Nitrogen Storage of Vegetation–Soil System in Sandy Grasslands: How Habitat Types Affect C and N Allocation? *Ecol. Evol.* **2021**, *11*, 9079–9091. [CrossRef]
46. Li, B.; Zhang, Y.; Yao, Y.; Dang, P.; Farooq, T.H.; Wu, X.; Wang, J.; Yan, W. Effects of Vegetation Restoration on Soil Nitrogen Fractions and Enzyme Activities in Arable Land on Purple Soil Slopes. *Plants* **2023**, *12*, 4188. [CrossRef]
47. Sun, J.; Jin, L.; Li, R.; Meng, X.; Jin, N.; Wang, S.; Xu, Z.; Liu, Z.; Lyu, J.; Yu, J. Effects of Different Forms and Proportions of Nitrogen on the Growth, Photosynthetic Characteristics, and Carbon and Nitrogen Metabolism in Tomato. *Plants* **2023**, *12*, 4175. [CrossRef]
48. Jobbágy, E.G.; Jackson, R.B. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* **2000**, *10*, 423–436. [CrossRef]
49. Hu, Y.; Liu, X.; He, N.; Pan, X.; Long, S.; Li, W.; Zhang, M.; Cui, L. Global Patterns in Leaf Stoichiometry across Coastal Wetlands. *Glob. Ecol. Biogeogr.* **2021**, *30*, 852–869. [CrossRef]
50. Kuglerová, L.; Dynesius, M.; Laudon, H.; Jansson, R. Relationships Between Plant Assemblages and Water Flow Across a Boreal Forest Landscape: A Comparison of Liverworts, Mosses, and Vascular Plants. *Ecosystems* **2016**, *19*, 170–184. [CrossRef]

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