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Response of Plant Species Diversity to Flood Irrigation in the Tarim River Basin, Northwest China

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Abstract: This study quantitatively analyzes the effects of flooding on the growth and species diversity of riparian forests along the Yarkant River and the Tarim River, Xinjiang, in northwest China, and provides important information for the efficient utilization of water and water resource management in arid regions. Monitoring of species diversity of riparian forests was conducted every year from 2016 to 2019 in the *Xiamale* forest district in the lower reaches of the Yarkant River, and in the *Shaya* forest district and the *lunnan* forest district in the upper and middle reaches of the Tarim River. The Pielou index, Shannon–Wiener index, Simpson index, and importance value were used to analyze the influence of flooding. The results showed the following: (1) After three years of flooding, indices for the lower reaches of the Yarkant River and Tarim River were significantly increased and 11 new plant species appeared. (2) With increasing distance from the river channel, plant density and species diversity decreased. Flooding trends are the main factors affecting the distribution of plant species and water is the main restricting factor that influences plant growth in arid areas; thus, desert riparian forests improved significantly after flooding. (3) Flooding increases the regeneration capacity and species diversity of plant communities in desert riparian forests. In order to maintain the current trend of ecological improvement, flooding irrigation must continue.

Keywords: flood irrigation; species diversity; desert riparian forests; Yarkant River; Tarim River

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1. Introduction

Riparian forests have provided many ecosystem services to humans for thousands of years. Their role in maintaining biodiversity and stream channel health is more important in semi-arid and arid regions [1]. Desert riparian forests play a crucial role in preventing sandstorm disasters, regulating local climate, and maintaining ecological safety in arid areas [2–4]. However, desert riparian forests today face a serious threat from various development activities [5]. It is time to restore these forests, since they support unique biodiversity and since their restoration will help in attaining local sustainable development [6]. There are many strategies for restoring riparian ecosystems. González et al. [6] and Mohan et al. [7] reviewed various strategies followed for the restoration of riparian ecosystems. These are hydro-geomorphic in nature, including steps such as active plant introduction, exotic species control, conversion to a natural floodplain, grazing and herbivory control, water quality improvement, and soil remediation. For these restoration projects, it is important to understand change in desert riparian ecosystems, successful approaches for their restoration, and limitations to better implementation of riparian ecosystem restoration around the world.

As an important factor affecting the stability of desert riparian ecosystems in arid areas, water can change the growth condition structure and plant species diversity of desert riparian forests [8]. Species diversity and productivity also play important roles in maintaining ecosystem stability and biodiversity [8]. Studying the relationships between plant species diversity and water environment factors has been a central issue for decades in ecology, providing important theoretical information for desert riparian forest conservation. Flooding is the most typical disturbance that greatly affects vegetation patterns. Flood pulses cause the plant habitats to change seasonally from terrestrial to aquatic environment, exerting considerable stress on plants [6]. Plants inhabit specific positions along hydrological gradients, reflecting their flood stress tolerance [7]. Flooding also has been considered as the driving force that affects soil physicochemical properties and vegetation change [8–10]. Thus, river flooding is widely used in vegetation reconstruction [9]. Fraser and Karnezis [10] compared fourteen wetland plant species grown under minor water-depth differences. Vervuren et al. [11] conducted river flooding experiments in the Rhine River during flood events in German. Arias et al. [12] proposed a conceptual hydro-ecological model to explain the disturbance mechanisms driving species diversity across large river floodplains in tropical rivers. Most studies have focused on the effects of natural river flooding on plant communities. Artificial flooding experiments for restoring destroyed riparian ecosystems at large areas scale are rare due to the uncommon occurrence of floods in arid areas.

Saving *Populus euphratica* forests by artificial flooding has been implemented in the Tairm river in northwest China. Many researchers had interested in "Saving *Populus euphratica* forest plan by artificial flooding" in the Tarim River basin and have explored the effects of river overflow disturbances and the water conveyance on plant restoration. For example, the effects of overflow on the composition, distribution, and diversity of plant communities were investigated [13–18]. Some scholars have researched the impact of overflow disturbance on plant communities and their restoration in the Tarim River basin. They explored how water conveyance in the main river channel affects the radial growth, species diversity, population structure, physiological characteristics, and ecological benefits of desert riparian forest in the lower reaches of the Tarim River [19–22]. These studies provide good advice and measures for improvement in the Tarim River basin. However, the "Saving *Populus euphratica* forest plan" has been implemented for many years. How did plant species change, and which environmental factors can cause plant species to change? Few studies focus on these questions.

The aim of this study is: (1) to analyze plant species diversity change after flooding irrigation; (2) to explain the effects of flooding irrigation on the plant diversity of desert riparian forests in typical areas. This study is expected to yield an improved understanding of the hydrological effects on the desert riparian forest in the Tarim River basin and provide experimental evidence that appropriate flooding irrigation impacts the plant species composition of riparian forests, providing tools for the prediction of anthropic impacts and the ecological restoration of desert riparian ecosystems.

2. Materials and Methods

2.1. Study Area

The study area is located in the Tarim River basin, Xinjiang, in northwest China (34°50′–43°08′ N, 73°10′–94°05′ E) (Figure 1). It is a typical arid continental climate characterized by strong annual evaporation and scarce precipitation [23,24]. The average annual temperature is 10.5–11.4 °C, the average annual precipitation is 30–50 mm, and the annual potential evaporation is between 2000–2900 mm. The drought index is 28–80 [25,26]. The desert riparian forest has an obvious structure of trees, shrubs, and grasses in the study area [27]. The main tree species are *Populus euphratica* and *Populus pruinose*. The shrubs are mainly *Taraxacum chinensis*, *Lycium ruthernicum, and Halimodendron halodendron*. The herbs are mainly *Phragmites communis, Poacynum Henderson*, and *Glycyrrhiza uralensis* [28,29].

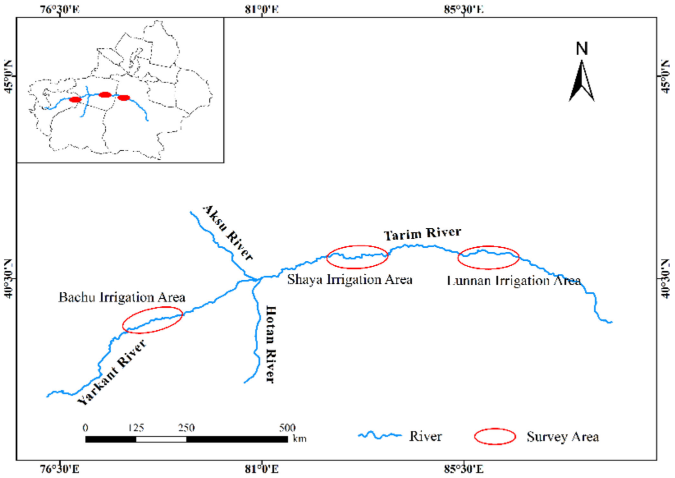

Figure 1. Map of the study area.

With intensified disturbance from human activities and irrational water resources utilization, groundwater levels have dropped obviously and resulted in serious degradation of the natural riparian forests [30,31]. Many *Populus euphratica* have disappeared; young *Populus euphratica* have difficult regenerating, leading to the decline of species diversity in the Tarim River basin [32]. In order to restore and protect the fragile desert riparian forest ecosystem, the Xinjiang government implemented the "Saving *Populus euphratica* forest plan", and began flooding irrigation for *Populus euphratica* forests in the Tarim River basin in 2017. Our studies focus on three typical areas where flooding occurs every year: the *Xiamale* forest district in the lower reaches of the Yarkant River, and the *Shaya* forest district and the *lunnan* forest district in the upper and middle reaches of the Tarim River, respectively.

2.2. Sampling Design

Summer is the flood season in the Tarim River basin. Flooding irrigation was also implemented for *Populus euphratica* forests every year during the study period. In this study, vegetation growth, species number, soil, and flooding monitoring were conducted three times in the June 2016, 2017, 2018, and 2019. The monitoring data of 2016a reflect the original state and were defined as the control group before flooding. The data of 2017a, 2018a, and 2019a reflect the vegetation change and were defined as experimental groups after flooding irrigation to conduct a statistical evaluation of the species in flooding quadrats and control quadrats using the plot survey method [33].

In each forest district, three quadrats were arranged in the direction of the vertical river channel. Four tree quadrats (25 m × 25 m) were selected at intervals of 150–200 m along each transect. Two shrub quadrats (5 m × 5 m) and three herb quadrats (1 m × 1 m) were randomly sampled in each tree quadrat. There were 29 tree quadrats, 58 shrub quadrats, and 87 herb quadrats in the study areas.

2.3. Monitoring Indexes Selection

In each tree quadrat, diameter at breast height, crown width, and height of each *Populus euphratica* were measured using a measuring tape and a Blume–Leiss altimeter. The tree growth status was assessed in Table 1. According to previous studies [34], young, medium, and old *Populus euphratica* were defined by DBH values of ≤10 cm, ≤30 cm, and ≤70 cm, respectively. The three *Populus euphratica* seedling quadrats (1 m × 1 m) were randomly selected to calculate the density of each tree quadrat.

Table 1. The growth grade standards of *Populus euphratica*.

Growth Grade	**Score**	**Growth Status and Morphological Characteristics of *Populus eupratica***
Excellent	8–10	Trees are in good shape and mainly composed of plump primary crowns, with little damage; they have dark green leaves and a crown loss of less than 10% in most cases.
Good	6–8	Growth status is good and trees are largely composed of defective compound crowns; the withered part of the trunk accounts for 1/4 of the whole tree; leaves are light-colored and crown loss remains within 11–25%.
Moderate	4–6	Growth in moderate conditions, showing the coexistence of primary and secondary crowns; withered parts of the trunk exceed 1/3 of the whole tree; the crown loss remains within 26–50%.
Relatively poor	2–4	Most trees have secondary crowns with obvious defects; withered parts of the branches and trunk exceed 2/3 of the whole tree; the crown loss is within 51–75%.
Poor	0–2	The primary crowns are nearly decayed, while secondary crowns are still underdeveloped; withered parts of the branches, trunk, and shoots exceed 3/4 of the whole tree; there are only a few leaves and crown loss is between 76–100%.

The crown width and height of each shrub (or cluster) were measured using a measuring tape in each shrub quadrat. The total branch number and 3–5 standard branches of each shrub were recorded. The new shoot lengths of each shrub at certain distances from the river channel (200–500 m) were monitored.

Species richness, number of each species, and height were recorded in each herb quadrat.

2.4. Data Analysis

Species diversity was measured by the evenness index (Pielou), dominance index (Shannon–Wiener), and diversity index (Simpson). Species diversity indexes are used to describe the disorder and uncertainty in the occurrence of individuals of species, i.e., the higher the uncertainty, the higher the diversity. The evenness index reflects the evenness of the distribution of the abundance (frequency, coverage, or other indexes) of different species within the community, as shown by Equations (1)–(3) [35]:

Pielou index:

$$E = -\frac{\sum P_i \ \ln P_i}{\ln S} \tag{1}$$

Shannon–Wiener index:

$$H = -\sum P_i \cdot \ln P_i \ ; \ \ P_i = N_i / N \tag{2}$$

Simpson index:

$$D = 1 - \ln\left(\sum P_i\right)^2 \tag{3}$$

where S represents the number of species, N represents the total number of individuals of all species, N_i represents the number of individuals of plant i, and P_i represents the frequency of occurrence of a certain species.

The important value (*IV)* measures the relative importance of different species in a community. Using *IV* can avoid overestimating the role of plant species that are small but large in quantity within a community. The reason is that substantial differences exist among different plant individuals (size and quantity). Therefore, *IV* provides an important basis to determine whether a specific species is the constructive, dominant, or a companion species in the community [36]:

$$IV = (relative\ height + relative\ coverage + relative\ frequency)/3 \tag{4}$$

where relative height = (the height of each species/the total height of all species) × 100%, relative coverage = (the coverage of each species/the total coverage of all species) × 100%, and relative frequency = (the frequency of each species/the total frequency of all species) × 100%. Data analysis was conducted using Canoco 5.0 software and Excel.

Canonical correspondence analysis (CCA) is an important ranking method to analyze the relationship between plant communities and environmental factors. Two databases of community vegetation and environmental factors are required for ranking CCA, and the relationships between plant species and environmental factors were calculated and analyzed by the CANOCO for Windows 4.5 software package. In this study, the CCA ranking method was used to analyze the specific relationships between plants and environmental factors based on the investigated data of the 29 quadrats and environmental factors. The environmental factors selected were: amount of flooding (Fi), vegetation cover (G), biomass, groundwater level, soil water content (SWC), soil salt content (SC), and soil organic matter content (SM) at different depths.

3. Results

3.1. Changes in Plant Species Diversity before and after Flooding

After three years of flooding, we found that there were 25 plant species after flooding for three years while there were 14 species before flooding (Table 2). It was found that there were mainly Leguminosae, Compositae, Gramineae, Tamaricaceae, Chenopodiaceae, and Salicaceae plants in the study areas. The life forms were dominated by perennial herbs (71%), shrubs (14%), and annual herbs (9%) before flooding. After flooding, 11 new species appeared including annual herbs, perennial herbs, subshrubs, and shrubs.

Table 2. Monitoring plant species before and after flooding irrigation in the study areas.

No.	Species Name	Life Form	Before Flooding	After Flooding
1	*Alhagi sparsifolia*	Subshrub	+	+
2	*Halostachys caspica*	Shrub	+	+
3	*Halimodendron halodendron*	Shrub	+	+
4	*Lycium ruthernicum*	Shrub	+	+
5	*Inula salsoloides*	Subshrub	+	+
6	*Apoacynum hendersonii*	Subshrub	+	+
7	*Artemisia scoparia*	Perennial herb	+	+
8	*Phragmites communis*	Perennial herb	+	+
9	*Acroptilon repens*	Perennial herb	+	+
10	*Oxytropis glabra (Lam.)*	Perennial herb	+	+
11	*Karelinia caspica*	Perennial herb	+	+
12	*Potentilla chinensis*	Perennial herb	+	+
13	*Glycyrrhiza inflata*	Perennial herb	+	+
14	*Hexinia polydichotoma*	Perennial herb	+	+
15	*Populus euphratica*	Tree		+
16	*Sophora alopecuroides*	Annual herb		+
17	*Salsola collina*	Annual herb		+
18	*Poa annua*	Annual herb		+
19	*Cirsium segetum*	Perennial herb		+
20	*Taraxacum mongolicum*	Perennial herb		+
21	*Aeluropus pungens*	Perennial herb		+
22	*Scorzonera austriaca*	Perennial herb		+
23	*Cynanchum sibiricum*	Subshrub		+
24	*Tamarix ramosissima*	Shrub		+
25	*Tamarix hispida*	Shrub		+

3.2. Spatial Characteristics of Plant Species Diversity after Flooding

After flooding, the mean values of the Simpson index, Shannon index, and Pielou index were 0.20, 0.67, and 0.25, respectively, and all indexes increased compared to before flooding in the study areas (Figure 2). It was found that these indices and plant density first showed a decreasing trend with increasing river channel distance from 150 m to 300 m. However, the species diversity indices all were relatively increasing at 450 m from the river channel. The Simpson index, Shannon index, and Pielou index were 0.7, 1.4, and 0.9, respectively, and significantly higher than those at the river channel distances from 150 m, 300 m, and 600 m ($p < 0.05$). At over 600 m from the river channel, the Simpson index, Shannon index, and Pielou index declined to 0.2, 0.4, and 0.5, respectively.

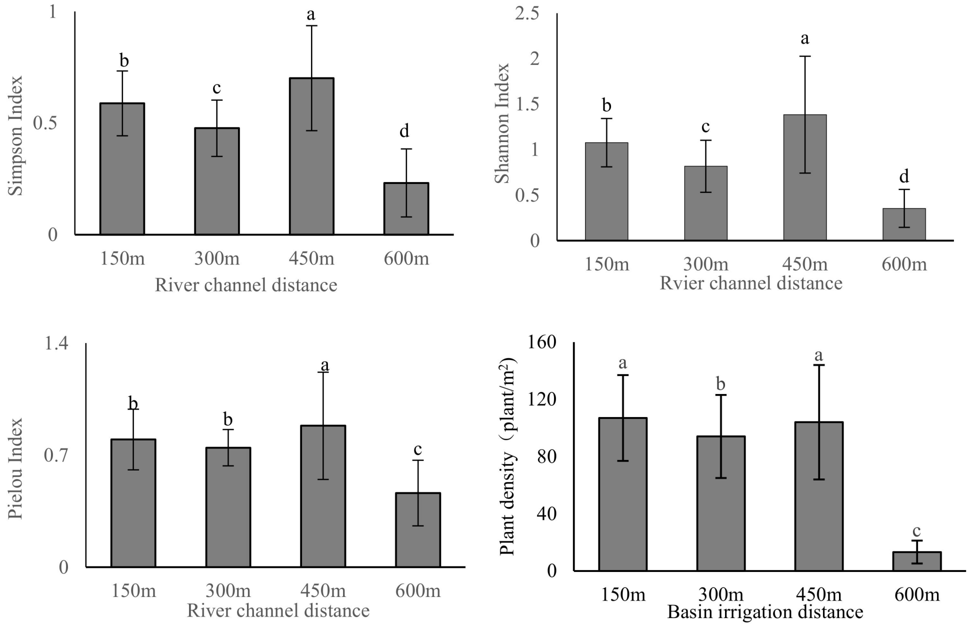

Figure 2. Species diversity changes at different distances from the river channel in the lower reaches of the Yarkant River (a, b, c is significant differently).

The descending order of plant density is as follows: 150 m > 450 m > 300 m > 600 m. These results suggest that the highest species richness appeared at 450 m from the river channel and the highest plant density appeared at 150 m from the river channel.

Considering the species diversity change at increasing distances from the river channel, a decreasing trend in the Simpson, Shannon, and Pielou indices is evident (Figure 3).

The Simpson and Shannon index were significantly higher at 150 m from the river channel compared to the other distances. ($p < 0.05$). For the Pielou index, there are no significant differences at 300 m and 450 m from the river channel. These results can be explained by the effects of flooding.

Additionally, the important value (*IV*) of shrubs and perennial herbs gradually increased, but the annual herbs or hygrophilous plants gradually decreased with increasing distance from the river channel in the lower reaches of the Yarkant River (Table 3). There were almost no annual plants beyond 600 m from the river channel. Within the distance from 150 m to 600 m, the plant communities were *Populus euphratica* + *Sophora alopecuroides* + *Potentilla chinensis* + *Gramineae* + *Glycyrrhiza uralensis* + *Cirsium*, *Populus euphratica* + *Tamarix chinensis* + *Gramineae* + *Glycyrrhiza uralensis* + *Crypsis aculeata*, *Populus euphratica* + *Tamarix chinensis* + *Glycyrrhiza uralensis* + *Taraxacum mongolicum* + *Oxytropis*, and the *Populus euphratica* + *Tamarix chinensis* + *Halostachys caspica* +*Phragmites communis*.

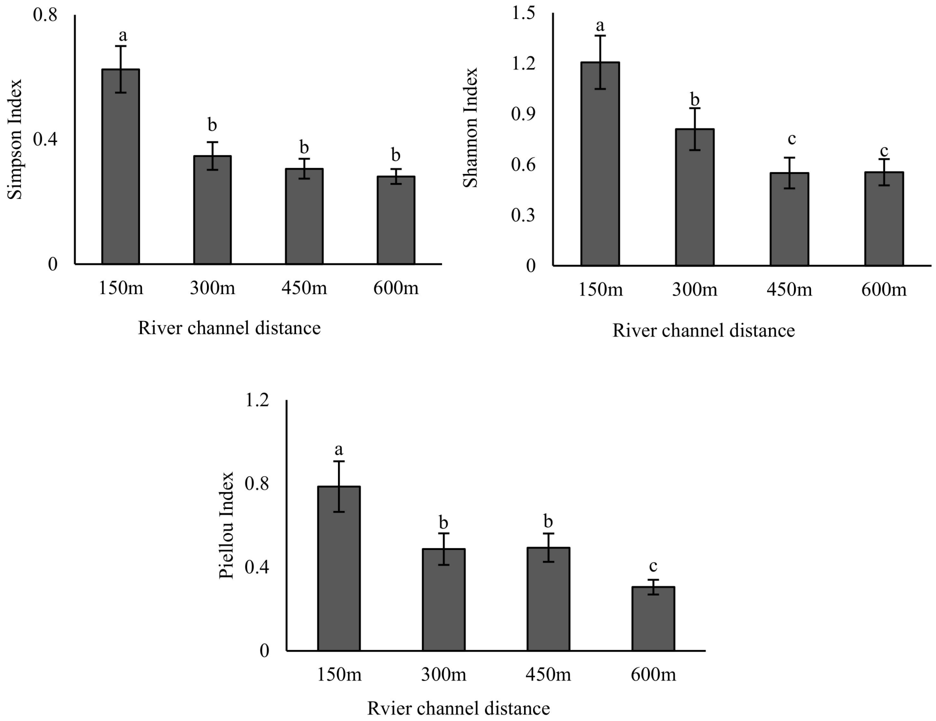

Figure 3. Species diversity changes at different distances from the river channel in the upper and middle reaches of the Tarim River. (a, b, c is significant differently).

Table 3. The important values of species at different distances from the river channel in the lower reaches of the Yarkant River.

Flooding Distance	Species	Important Value	Flooding Distance	Species	Important Value
150 m	*Sophora*	0.35	300 m	*Populus euphratica*	0.33
	Populus euphratica	0.23		*Phragmites australis*	0.22
	Potentila chinensis	0.15		*Gramineae sp.*	0.21
	Gramineae sp.	0.10		*Glycyrrhiza uralensis*	0.11
	Populus euphratica	0.10		*Tamarix ramosissima*	0.04
	Glycyrrhiza uralensis	0.05		*Populus euphratica*	0.04
	Cirsium sp.	0.01		*Leguminosae sp.*	0.02
	Cynanchum sibiricum	0.00		*Crypsis aculeata*	0.02
	Poa annua	0.00		*Karelinia caspia*	0.01
	Alhagi sparsifolia	0.00		*Apocynum venetum*	0.01
	Taraxacum sp.	0.00		*Calamagrostis*	0.00
	Acroptilon repens	0.00			
450 m	*Cynodon dactylon*	0.21	600 m	*Tamarix ramosissima*	0.44
	Phragmites australis	0.21		*Populus euphratica*	0.28
	Sophora	0.19		*Phragmites australis*	0.14
	Populus euphratica	0.19		*Tamarix ramosissima*	0.08
	Tamarix ramosissima	0.07		*Halostachys caspica*	0.05
	Glycyrrhiza uralensis	0.06		*Lycium ruthernicum*	0.01
	Taraxacum sp.	0.02		*Halimodendron*	0.00
	Oxytropis sp.	0.02		*Aeluropus pungens*	0.00
	Gramineae sp.	0.01			
	Scorzonera austriaca	0.01			
	Tamarix	0.01			
	Populus euphratica	0.01			
	Salsola collina	0.00			
	Inula salsoloides	0.00			
	Apocynum venetum	0.00			
	Lactuca sativa	0.00			

Within 150 m from the river channel, the IV of *Sophora alopecuroides* (annual herbs and hygrophilous plants) was the highest, signaling that this was a dominant species. Its density was 54 plants/m^2. *Sophora alopecuroides* and *Gramineae* appeared less and their density was 15 clusters/m^2. At 300 m from the river channel, the IV of Gramineae was the highest and many *Gramineae* appeared. Within a flooding distance of 450 m, *Cynodon dactylon* (hygrophilous plants) had the highest IV and was the dominant species in this area. At 600 m from the river channel, the IV of *Phragmites communis* was the highest. *Tamarix chinensis*, a drought-tolerant species, gradually increased at 450 to 600 m, but *Populus euphratica* was still the dominant species in the study area. At 300 m from the river channel, *Sophora alopecuroides* and *Gramineae* have a competitive advantage and are inhibited by the other herbs together. The area 450 m from the river channel was a transitional area of species change and had relatively higher species diversity. At 600 m from the river channel, drought-tolerant *Populus euphratica*, *Tamarix chinensis*, and *Halostachys caspica* became dominant species.

The dominant species and their IVs were investigated at different distances from the river channel in the upper and middle reaches of the Tarim River after three years of flooding (Table 4). The species richness shows a decreasing trend with increasing distance from the river channel. Many seedlings of *Tamarix chinensis* and *Populus euphratica* began to germinate after three years. Their IVs were 0.29 and 0.19, respectively, within 150 m from the river channel. indicating the importance of water supply for plant growth. Herbs germinated greatly, including some perennial herbs (*Phragmites communis* and *Halimodendron halodendron*, with an IV of 0.167), some hygrophilous plants (*Cynanchum sibiricum* and *Scorzonera austriaca*, with an average IVs of 0.05), and annual herbs (*Sophora alopecuroides*, with IV of 0.012).

Table 4. Comparison of important values of species with different life forms in the upper and middle reaches of the Tarim River at different irrigation distances from the river channel.

Flooding Distance	Species	Important Value	Flooding Distance	Species	Important Value
150 m	*Tamarix ramosissima*	0.30	300 m	*Tamarix ramosissima*	0.20
	Populus euphratica	0.19		*Taraxacum*	0.14
	Phragmites communis	0.09		*Lycium ruthernicum*	0.13
	Halimodendron halodendron	0.08		*Tamarix ramosissima*	0.12
	Populus euphratica	0.07		*Scorzonera austriaca*	0.11
	Acroptilon repens	0.06		*Populus euphratica*	0.11
	Leguminosae sp.	0.05		*Populus euphratica*	0.10
	Scorzonera austriaca	0.04		*Phragmites communis*	0.03
	Tamarix ramosissima	0.03		*Poa annua*	0.02
	Cynanchum sibiricum	0.02		*Alhagi sparsifolia*	0.01
	Gramineae sp.	0.02		*Potentilla chinensis*	0.01
	Alhagi sparsifolia	0.02		*Cynanchum sibiricum*	0.01
	Sophora alopecuroides	0.01		*Acroptilon repens*	0.01
	Lycium ruthernicum	0.01		*Glycyrrhiza inflata*	0.00
	Taraxacum	0.01		*Hexinia polydichotoma*	0.00
	Scorzonera austriaca	0.00			
	Artemisia sp.	0.00			
	Halostachys caspica	0.00			
	Karelinia caspica	0.00			
450 m	*Phragmites communis*	0.33	600 m	*Glycyrrhiza inflata*	0.29
	Tamarix ramosissima	0.22		*Tamarix ramosissima*	0.29
	Lycium ruthernicum	0.20		*Populus euphratica*	0.16
	Alhagi sparsifolia	0.09		*Alhagi sparsifolia*	0.10
	Populus euphratica	0.06		*Halimodendron halodendron*	0.07
	Artemisia sp.	0.05		*Sophora alopecuroides*	0.03
	Potentilla chinensis	0.03		*Lycium ruthernicum*	0.03
				Phragmites communis	0.02

At 300 m from the river channel, the seedlings of *Populus euphratica* and *Tamarix chinensis* had relatively higher IV (0.196 and 0.2, respectively), suggesting the significance of water supply effect on the breeding and regeneration of dominant species in this distance range. Ranking IVs, these were followed by perennial herbs (with an IV of 0.125, mainly *Taraxacum mongolicum and Scorzonera austriaca*) and shrubs (with an IV of 0.125, mainly *Lycium ruthenicum*). However, the IVs of drought-intolerant species (e.g., *Cynanchum sibiricum, Potentilla griffithii, and Lactuca sativa*) and hygrophilous plants showed a significant decreasing trend. There were also a few annual herbs such as *Poa annua* (with an IV of 0.017) at this distance away from the river channel.

At 450 m from the river channel, the IV of *Populus euphratica* seedlings decreased abruptly (only 0.056), annual herbs gradually disappeared, and hygrophilous plants (e.g., *Cynanchum sibiricum, Lactuca sativa,* and *Potentilla griffithii*) decreased. In contrast, the IVs of drought-tolerant species (e.g., *Phragmites communis*, *Tamrix chinensis*, *Lycium ruthenicum*, and *Alhagi sparsifolia*) increased gradually.

At 600 m from the river channel, annual herbs such as *Populus euphratica* and *Tamarix chinensis* disappeared. Perennial herbs including *Glycyrrhiza uralensis* and *Tamrix chinensis* and shrubs became dominant species at this distance from the river channel.

3.3. Relationship between Plant Species Diversity and Environmental Factors

The results of the CCA simulation are reported in Figures 4 and 5. The environmental factor and species diversity index are represented by a line with an arrow. The length of the line indicates the correlation between plant species diversity and the environmental factor. The angle between the arrow line and the sort axis indicates the correlation between the environmental factor and the sort axis, and the direction indicated by the arrow indicates the changing trend of the environmental factor.

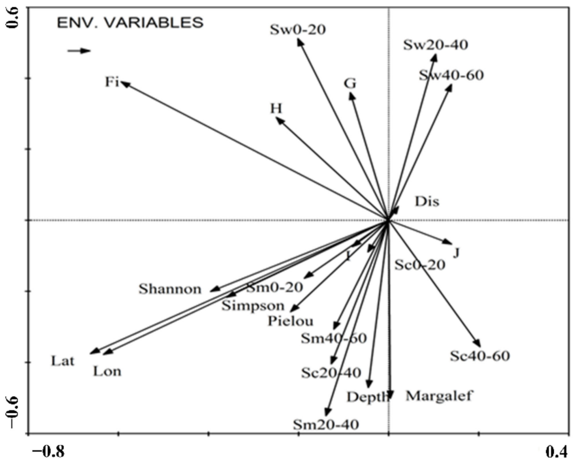

Figure 4. The correlation between environmental factors and plant species diversity.

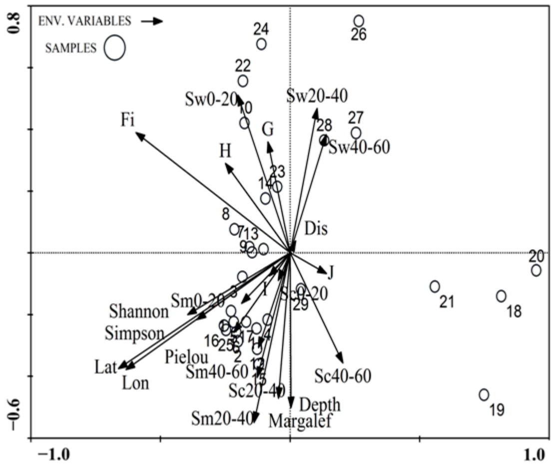

Figure 5. The correlation between the quadrat distribution and environmental factors.

From left to the right along the horizontal axis of the CCA, the SWC at 20–40 cm depth, the SC at 40–60 cm depth, and the mean height of *Populus euphratica* all increased with increasing distance from the river channel (Figure 4). Plant species diversity showed strong correlations with the above environmental factors. From bottom to top along the vertical axis of the CCA, the SC at 0–60 cm depth, G, and the biomass of herbaceous plants all showed an increasing trend. The SWC at 0–60 cm depth, SM at 0–60 cm depth, the height of *Populus euphratica*, species diversity indices, and Fi showed a decreasing trend.

The flooding trend was the main factor that affected plant community distribution. Fi was positively correlated with SWC at 0–60 cm depth, G, and biomass of herbaceous species. Both SC and SM at 0–60 cm depth were positively correlated with groundwater depth and biodiversity indices. These results indicated that, with increasing groundwater levels, the Margalef index, SM, and SC all showed a significantly increasing trend. Moreover, with increasing longitude and latitude, the Simpson, Shannon, and Pielou index showed a significantly increasing trend. SWC was negatively correlated with SM and SC. Species diversity was strongly correlated with Lat, Lon, SM, and SC.

Fi, the amount of flooding; G, vegetation cover; Sw, soil water content; Sc, soil salt content; Sm, soil organic matter content; H, the diameter at breast height; Lon, longitude; Lat, latitude.

The correlation between quadrat distribution and environmental factors is reported in Figure 5. The SWC at 0–60 cm depth greatly affected the distribution of quadrats in the lower reaches of the Yarkant River (22, 24, 26, 28, and 27), at 600 m from the river channel in the middle reaches of the Tarim River (10), and at 600 m from the river channel in the middle reaches of the Tarim River (14).

Alhagi sparsifolia, Sophora alopecuroides, and *Cirsium* were included in quadrats of 8, 10, and 14 at 300–600 m from the river channel in the middle reaches of the Tarim River. The values of SWC, SM, and SC were 10.5%, 5.54 g/kg, and 0.59 g/kg, respectively. *Taraxacum mongolicum, Poa annua, Potentilla chinensis, Lactuca sativa, Cynodon dactylon, Oxytropis*, and *Inula salsoloides* were included in quadrats of 7, 11, 12, 13, and 22 at 150 m from the river channel in the lower reaches of the Yarkant River and at 150–450 m from the river channel in the middle reaches of the Tarim River. The values of SWC, SM, and SC were 10.1%, 4.56 g/kg, and 0.27 g/kg, respectively. *Russian knapweed* and *Cynanchum sibiricum* were included in quadrat 24 at 450 m from the river channel in the lower reaches of the Yarkant River. The values of SWC, SM, and SC were 13.5%, 4.56 g/kg, and 0.27 g/kg, respectively. *Crypsis aculeata*, *Halimodendron halodendron, Lycium ruthernicum, and Aeluropus pungens* were included in quadrants 27 and 28 at 300–450 m from the river channel in the lower reaches of the Yarkant River. The values of SWC, SM, and SC were about 14.7%, 5.85 g/kg, and 0.48 g/kg, respectively.

The quadrats were greatly affected by SC and SM at 600 m from the river channel in the middle reaches of the Tarim River (2, 4, 11, 12 and 25) and in the upper reaches of the Tarim River (15, 16, and 17). This indicates that these quadrats were less affected by flooding irrigation and had relatively higher SC and Sm. With increasing distance from the river channel, SC and SM showed an increasing trend. The SC was higher in the lower reaches of the Yarkant River than in the upper and middle reaches of the Tarim River. The quadrats in the Yarkant River (18, 19, 20, and 21) were greatly affected by groundwater level and SC at 40–60 cm depth. In other words, with greater distance from the river channel, the groundwater was deeper and SC at 40–60 cm depth was higher.

Gramineae sp. is included in quadrats 1, 9, and 23 at 150–450 m from the river channel in the middle reaches of the Tarim River and at 300 m distance in the lower reaches of the Yarkant River. The values of SWC, SM, and SC were 9.5%, 3.64 g/kg, and 0.0025 g/kg, respectively. *Karelinia caspica, Sonchus oleraceus, Apocynum venetum, Leguminosae sp*., and *Calamagrostis pseudophragmites* were present in quadrats 15, 16, 17, and 29 at 150–300 m from the river channel in the upper reaches of the Tarim River and at 600 m distance in the lower reaches of the Yarkant River. The values of SWC, SM, and SC were about 8.1%, 3.67 g/kg, and 0.22 g/kg, respectively. *Populus euphratica* and *Lycium ruthenicum* were included in quadrats 2, 5, and 6 at 150–300 m distance in the middle reaches of the Tarim River. The values of SWC, SM, and SC were 7.7%, 3.7 g/kg, and 0.26 g/kg, respectively. *Phragmites communis* and *Scorzonera austriaca* were included in quadrats 3, 4, and 25 at 400–600 m distance in the lower reaches of the Yarkant River. The values of SWC, Sm, and SC were 12.3%, 5.85 g/kg, and 0.48 g/kg, respectively. *Halostachys caspica*, *Salsola collina*, and *Populus pruinosa* were included in quadrants 20 and 21 at 450–600 m distance in the lower reaches of the Yarkant River. The values of SWC, SM, and SC were 7%, 4.9 g/kg, and 0.35 g/kg, respectively.

4. Discussion

4.1. The Effect and Function of River Flooding on Plant Species Diversity

The success of the restoration of the desert riparian ecosystem is influenced by various factors including biotic, abiotic, social, and governance aspects [5,7]. River flooding, a main abiotic factor, may have significant value to riparian ecosystem restoration. The intensity and frequency of floods may significantly influence the regeneration of forests. Human interventions such as damming and controlling floods can change the growth of riparian plants [37,38]. In arid areas, changes depend purely on groundwater, whereas in other regions, they depend on the surface water flow [39]. However, changes in groundwater levels may take years to become evident; hence, effectively increasing the surface water flow through flooding irrigation in short periods for the restoration of riparian ecosystems is important, and may provide insights into the adaptability of the ecosystem.

Compared to before flooding, herbs grew better and vegetation coverage and species diversity also increased after flooding due to the flooding process activating the soil seed banks in the study areas. Flooding irrigation replenishment from May to September every year will provide opportunities to increase the probability of seed germination [40]. The seeds and roots of annual herbs and specific hygrophilous plants grow in shallow-layer soil. Therefore, it is indicated that flooding irrigation could increase soil water content and form favorable conditions for seed germination (or root turion growth). This result is similar to those of other studies [41]. Arias et al. [12] and Hazelton et al. [42] also discovered that the spatial interaction between the natural flood regime and upland factors creates patterns of disturbance gradients that influence how floodplain vegetation is established. In regions where upland conditions are subject to strong external disturbances, species diversity peaks at intermediate stages along the disturbance gradient.

In the Tarim River, artificial flooding irrigation is essential and effective for the restoration of riparian forests. After three years of the flooding, *Populus euphratica* (seedlings) and other salt-intolerant species emerged in the study area, suggesting that flooding irrigation decreased soil salt content and may have had a salt-leaching effect [41]. Considering the low survival rate of seedlings, it was still necessary to actively provide long-term water replenishment, and regulate the water replenishment time. Long-term water replenishment could improve the environment for *Populus euphratica* growth, activate its seed banks, and promote the growth of sprout tillers. The time for seed germination of *Populus euphratica* was "highest in August, and gradually declining towards both sides" [43]. If there is no water replenishment the 20 days after the seeds of *Populus euphratica* fall, the seeds lose their activity and do not germinate [38]. It is important to select appropriate times for flooding irrigation for seed germination.

4.2. The Desert Riparian Forest Distribution after River Flooding Irrigation

Floods have a decisive influence on the structure, composition, and distribution patterns of riparian forests, and any disturbance in the water flow has a profound effect on these characteristics [44]. In the study areas, the distribution and aggregation intensity of plant species were relatively scarce with increasing distance from the river channel. As groundwater levels were higher closer to the river channel, *Sophora alopecuroides*, *Tamarix chinensis*, *Phragmites communis*, and *Gramineae* could grow in this area. Plant species diversity was higher, plant density was relatively higher, and plant distribution was more even. Beyond 600 m from the river, which was weakly affected by flooding, some shrubs, and subshrubs such as *Tamarix chinensis* and *Halostachys caspica* appeared and became dominant species in this habitat. With increasing distance from the river channel, annual herbs gradually disappeared; this area was dominated by salt-tolerant and drought-tolerant shrubs and short-lived herbs [45]. *Phragmites communis*, *Tamarix chinensis* (seedlings), and *Halostachys caspica* were observed, accompanied by *Tamarix chinensis* and *Populus euphratica*. The greater the distance from the river channel, the deeper the groundwater level and the lower the density of *Populus euphratica. Populus euphratica* increased aggregation intensity due to the germination of roots or branches around the seed trees [46].

This study suggests that flooding promotes the appearance of new species and greatly improves species diversity in this area. However, annual herbs and seedlings decreased sharply, and there were only eight species beyond 300 m from the river channel due to intense evaporation, deep groundwater level, and severe salinization. It was difficult to realize the transition from seedlings to young plants. These plants usually die within months after seed germination. The flood period of the Tarim River generally lasts from late July to early August, which coincides with the developmental phases of *Populus euphratica*, *Tamarix chinensis, Phragmites communis*, and *Alhagi sparsifolia* [47]. *Tamarix chinensis*, *Alhagi sparsifolia*, and other shrubs and subshrubs were dominant species and had deep roots and other drought-resistant characteristics [48].

To increase the effect of flooding irrigation, a network of water replenishment channels should be built to weaken the competitive advantage of hygrophilous plants, coordinate the mutually dependent relationships among trees, shrubs, and herbs, and improve the biodiversity of these areas. In addition, it is also necessary to increase the flooding flow rate and flood peak discharge, and to build new water transfer channels. This could provide large-scale conditions for *Populus euphratica* forests. In the future, the scope of flooding should be further expanded to extend runoff disturbances and groundwater disturbances to 600 m and 1000 m, respectively.

5. Conclusions

We discussed how artificial flooding irrigation can affect the riparian ecosystem, and validated the interaction between environmental factors and appropriate flooding irrigation. The results provide experimental evidence that floods impact the germination, species composition, and diversity of desert riparian forests. Appropriate flood disturbances can improve plant diversity and stability, confirming the “moderate interference theory” in restoration ecology. This study may provide a theoretical basis for improving the water replenishment plan in arid areas and realizing the efficient utilization of water resources in the future. According to our research, river flooding irrigation can recharge soil water to guarantee normal germination of some seeds. After three years of flooding, some new species appeared and species diversity indices such as the Simpson index, the Shannon–Wiener index, and the Pielou index all increased in the study areas. Artificial flooding irrigation was the main factor that affected plant distribution and growth. Desert riparian forests improved significantly after flooding irrigation. With decreasing groundwater levels, the Margalef index, soil organic matter content, and soil salt content all increased significantly. High evaporation moves organic matter and salts from deeper soil to the topsoil. The increased topsoil salt content may further restrain the normal growth of plants and decrease the richness of plant species. The plant species diversity indices showed a significant increasing trend from the lower reaches of the Yarkant River to the upper and middle reaches of the Tarim River. There is a wide channel and a freely swinging riverbed in the upper and middle reaches of the Tarim River, which create better water replenishment effects for soil and plants. Therefore, species diversity was higher in the upper and middle reaches of the Tarim River than in the lower reaches of the Yarkant River.

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