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Characteristics of Plant Community and Its Relationship with Groundwater Depth of the Desert Riparian Zone in the Lower Reaches of the Ugan River, Northwest China

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Abstract: The vegetation in the desert riparian zone represents a critical barrier in the maintenance of the ecosystem's balance. However, in recent years, the vegetation degradation of the riparian zone has seriously hindered economic development and ecological environment conservation. Based on a field investigation and literature, the mechanisms of vegetation degradation in the lower reaches of the Ugan River are discussed in this study through the analysis of plant coverage, diversity, substitution rate, distribution pattern, grey correlation analysis, and the relationship with groundwater depth. The results showed that the vegetation coverage in this region is relatively low when the water depth exceeds 4 m. Furthermore, the Shannon–Wiener index, the Simpson index, and the Pielou index all decreased with increases in water depth. Woody plants are the main species maintaining the ecological balance of the region with an aggregation distribution pattern. The degradation of vegetation is the result of the lack of water sources and the intense water consumption caused by human activities (especially agricultural). To promote ecological balance and vegetation restoration, the relative optimal water depth range should be maintained within 2 to 5 m as well as proper control of human activities. In addition, the degraded vegetation can gradually be restored using point and surface (i.e., flowering in the center and spreading to the surrounding areas). The results can provide a scientific basis for vegetation restoration and ecological conservation in the lower reaches of China's Ugan River.

Keywords: desert riparian zone; species diversity; degradation; grey relationship analysis

1. Introduction

Vegetation is a natural link that connects soil, air, and water. For example, Srivastava [1] and Fatichi [2] pointed out that vegetation is one of the key factors affecting soil moisture variability, while Liu showed that soil water availability is the primary control of plant transpiration under water deficit conditions [3]. Additionally, previous studies also indicated that afforestation increases the evapotranspiration of the soil–vegetation system and the consumption of groundwater resources, which leads to desertification [4]. Moreover, it can also indicate the health of a regional ecological environment and global change [5]. In fact, the interaction mechanisms between soil–vegetation–water–atmosphere is not totally clear.; As an important part of vegetation research, plant diversity has been widely researched by scholars [6]. Plant diversity not only reflects species composition, structural types, habitat differences, and stability of communities, but also the relationship between biological communities and environmental factors, which plays an important role in maintaining biodiversity, ecosystem structure, and function [7,8].

At present, research on the diversity of terrestrial plant communities has obvious regional characteristics and is mainly concentrated on mountainous areas [9], lakes [10,11], grasslands [12,13], forests [14,15], farmlands [16], and wetlands [17,18], etc. These studies could promote the development of biodiversity, enrich the content of diversity, and contribute to regional ecological conservation. For instance, plant functional diversity could drive mutualistic network assembly across an elevational gradient, restoring aquatic vegetation could help to increase the diversity of wintering waterbirds, and maintaining macrophyte diversity may enhance the functioning and associated services of wetland ecosystems [14]. However, few studies have focused on plant community diversity in desert areas of specific.

The Ugan River Basin located in Xinjiang, China, has a temperate continental climate. It is a typical arid area with a fragile ecological environment and desert habitat characteristics, but there is a lack of literature on plant community diversity in this region. Extant studies on the Ugan River Basin mainly focused on oasis agriculture/irrigation [19], soil salinization [20,21], heavy metal pollution [22], and cultivated land resource development [23]. Therefore, it is crucial to supplement and enrich past and current research in order to provide a theoretical basis for regional ecological conservation and economic sustainable development.

The riparian zone is an important habitat at river and land junctions, playing a key role in both the ecosystem and regional ecological environment construction [24]. In particular, the natural vegetation in these zones is important for maintaining ecosystem balance and regional economic development, such as windbreak and sand fixation, soil and water conservation, climate regulation, and air purification [25]. However, in recent years, with the aggravation of climate change and the effect of human factors [26], the riparian vegetation has been severely degraded and the stability and further development of the ecosystem have been threatened [27]. For these reasons, there is a clear and urgent need to speed up the restoration of riparian vegetation.

Desert riparian zones are generally more fragile habitats than riparian zones. The lower reaches of the Ugan River is a typical desert riparian zone. Its natural vegetation provides an important barrier for maintaining local ecological balance through windbreak and sand fixation; it also contributes significantly to the overall development of the oasis agriculture and the oasis economy. In recent years, however, the degradation of the natural vegetation and ecological environment has seriously hindered local economic development and ecological environment construction. In studying such issues, researchers have found that on a larger scale (i.e., major region or globally), climatic conditions are the main factors affecting vegetation type, survival, and lifespan [28], whereas on a smaller scale (e.g., landscape, watershed, community), environmental features such as topography, landform, salinity, nutrients, water, etc., are often the decisive factors [29,30].

Of the several environmental factors that affect vegetation growth in arid desert areas, water is one of the most important [31], as it directly affects the growth, development, and survival of plants. In turn, vegetation influences the partitioning of precipitation into evapotranspiration and runoff by intercepting the rainfall and retaining water through its roots. Gan [32] using the Budyko model showed that large scale revegetation can contribute 60% of the total observed change in the annual runoff, especially in water-limited regions. However, Huang [33] pointed out that the opposite effect of vegetation on streamflow and terrestrial water storage is weakened, which may lead to an overestimation of the effect of annual vegetation on streamflow. In arid areas, surface water and groundwater often serve as the important water sources of plants. However, due to global climate change and human activities on the lower reaches of the Ugan River, groundwater is now the only source for the plants.

It is crucial to understand how groundwater is distributed in the study area, as well as the distribution characteristics of plant communities and the relationship between plant communities and groundwater depth. The study analyses and discusses these issues using field sample survey data along with real-time dynamic monitoring data of groundwater depth. Specifically, plant coverage, diversity, substitution rate, distribution pattern, grey correlation analysis, and the relationship with groundwater depth are analyzed. Additionally, possible mechanisms of vegetation degradation are explored, and countermeasures discussed, providing a theoretical basis for vegetation restoration, ecological environment construction, and economic sustainable development in the lower reaches of China's Ugan River.

2. Materials and Methods

2.1. Study Area

The Ugan River Basin is situated between 41°06′ N–41°40′ N and 80°37′ E–83°59′ E, adjacent to the Tarim River Basin to the south and the Tianshan Mountains to the north. This region features a typical temperate continental climate characterized by minimal precipitation and strong evaporation. Annual average precipitation is less than 100 mm and its distribution is uneven across the seasons. The summer months (June to August) see the most precipitation for the year (60%–70%), with an evaporation drop ratio of about 40:1. In this regard, the study region is a typical arid zone in China [34]. In recent years, with the aggravation of climate change and the influence of human factors, the runoff has been insufficient to supply the needs of the river's lower reaches, bringing severe challenges to the sustainable development of the local economy and the construction of the ecological environment.

2.2. Research of Plot Setting

In order to ensure the survey sample plot comprehensively reflects the characteristics of the regional vegetation habitat, the principles of typicality, representativeness, and scientificity of the sample plot selection were employed following the field investigation. Specifically, 10 groundwater level monitoring wells, numbered WG1, WG2, WG3, etc., were set up along the lower reaches of the Ugan River (Figure 1). The vegetation around the monitoring wells was investigated from late July to early August 2019. The sample plot selection took into account the community types of the river reach. There were 24 samples in total, with a plot size of 50 × 50 m. Each plot was divided into four 25 × 25 m arbor and shrub quadrats. The species, quantity, plant height, crown width, diameter at breast height or basal diameter, and coverage of arbors and shrubs in the sample plots were determined, and 3–5 herbaceous quadrats (1 × 1 m) were randomly set in each arbor and shrub sample plot. The latitude, longitude, and altitude of each plot and monitoring well and its surrounding environment were recorded.

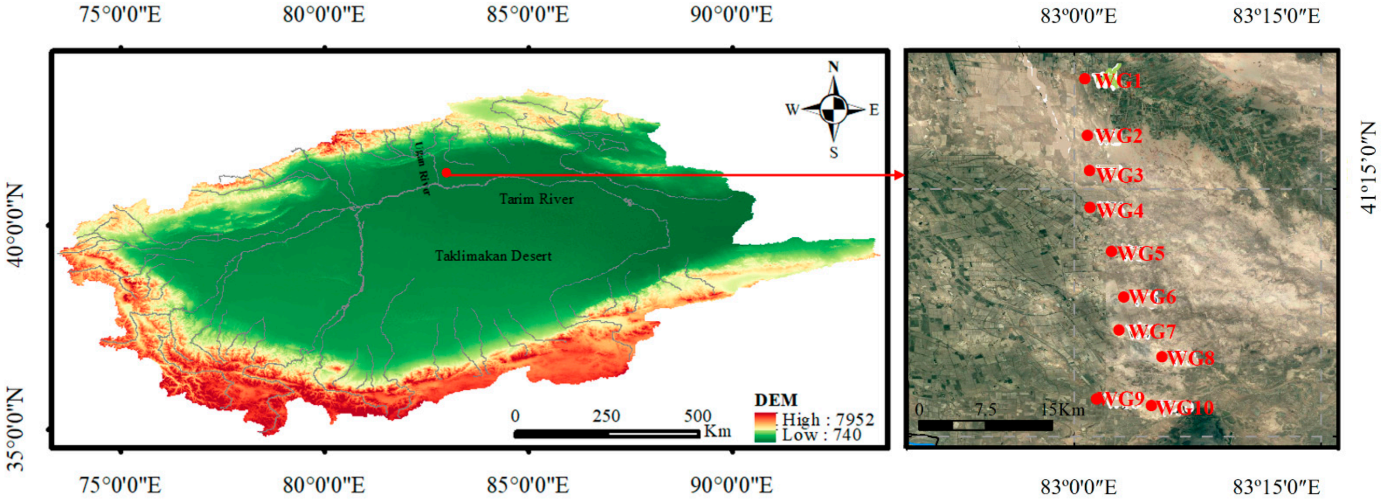

Figure 1. WG1, WG2, WG3, etc. are the monitoring wells which were set up along the lower reaches of the Ugan River.

2.3. Data Processing and Analysis Methods

In this study, the characteristics of plant communities were determined using the Margalef index, the Pielou index, the Simpson index, and the Shannon–Wiener index etc. [31], the substitution rate using the Cody index (β) [35], and the spatial pattern of dominant populations in the desert riparian zone of the lower reaches of the Ugan River analyzed by using the pattern indexes (diffusion coefficient (C, t test), mean crowding intensity (m^*), clumping index (I), Cassic index (C_a), and agglomerative index (PI)) [36]. The calculation formula is as follows:

Shannon–Wiener index:

$$H' = -\sum_{i=1}^{S} Pi \ln Pi \tag{1}$$

Simpson index:

$$D = 1 - \sum Pi^2 \tag{2}$$

Pielou index:

$$E = \frac{-\sum Pi \ln Pi}{\ln S} \tag{3}$$

$$\text{Margalef index D} = (S-1)/\ln \text{N} \tag{4}$$

$$\text{Patrick index R} = S \tag{5}$$

$$\text{Menhinick index M} = S/\text{SQRT}(\text{N}) \tag{6}$$

where P_i is the important value of species, S is the number of species in the quadrat, and N is the total number of individuals of all plants.

$$\beta = \frac{g(H) + I(H)}{2} \tag{7}$$

where $g(H)$is the number of species increasing along the habitat gradient, and $I(H)$ is the number of species decreasing along the habitat gradient.

Diffusion coefficient method (C):

$$S^2 = \frac{\sum x^2 - \frac{(\sum x)^2}{n}}{n-1}; A = \frac{\sum x}{n}; C = \frac{S^2}{A}. \tag{8}$$

where S^2 is the variance of the population dominant species abundance, A is the average value of the population dominant species abundance, x is the number of individuals observed in each quadrat, and n is the number of quadrats (the same letter, the same meaning below). When $C = 1$, it is random distribution; when $C < 1$, uniform distribution; and when $C > 1$, aggregation distribution. Among them, the t test ($t = (S^2/A - 1)/(2/(\text{n}-1))^{0.5}$ was used to determine the deviation degree between the actual measurement and the expectation.

Mean crowding intensity (m^*):

$$m^* = A + (C-1) \tag{9}$$

where m^* is the mean crowding intensity index, which represents the mean crowding intensity of individuals. The higher the m^* value, the greater the congestion.

Clumping index (I):

$$I = C - 1 \tag{10}$$

where, when $I = 0$, it is random distribution; when $I < 0$, uniform distribution; and when $I > 0$, aggregation distribution.

Cassic index (C_a):

$$C_a = \frac{S^2 - A}{A^2} \tag{11}$$

where, when $C_a = 0$, it is random distribution; when $C_a < 0$, uniform distribution; and when $C_a > 0$, aggregation distribution.

Agglomerative index (PI):

$$PI = \frac{m^*}{A} \tag{12}$$

where, when $PI = 1$, it is random distribution; when $PI < 1$, uniform distribution; and when $PI > 1$, aggregation distribution.

Grey correlation analysis is a research method that quantitatively compares the correlation degree of factors contained in a system [37]. In this study, the groundwater depth was taken as the characteristic sequence $X_0(k)$, and the indexes of species diversity were used as the factor sequence $X_i(k)$. The correlation coefficient and correlation degree were calculated after the initial value transformation, which could quantitatively reflect the relationship between plant community species diversity and groundwater depth, where k represents the spatial position. The calculation formula is as follows:

Correlation coefficient

$$\xi i(k) = \frac{\min\min|X0(k) - Xi(k)| + \rho \max\max|X0(k) - Xi(k)|}{|X0(k) - Xi(k)| + \rho \max\max|X0(k) - Xi(k)|} \tag{13}$$

Correlation degree

$$ri = \frac{1}{n}\sum_{k=1}^{n} \xi i(k) \tag{14}$$

where ρ is the resolution coefficient, with the value of 0.5; $\mid X_0(k) - X_i(k) \mid$ is the absolute value difference between the characteristic sequence and the factor sequence at the k point; $\min \mid X_0(k) - X_i(k) \mid$ is the minimum difference of the first order, which represents the minimum value of the difference between the corresponding points of the characteristic sequence and the factor sequence; and $\mathrm{minmin} \mid X_0(k) - X_i(k) \mid$ is the minimum difference of the second order, representing the minimum value of the first-order minimum difference. Furthermore, $\max \mid X_0(k) - X_i(k) \mid$ and $\mathrm{maxmax} \mid X_0(k) - X_i(k) \mid$ are grade 1 and grade 2 maximum differences, respectively, and their meanings are similar to the minimum difference: the larger the r_i value, the closer the correlation between factors.

3. Results

3.1. Distribution of Groundwater Depth in Different Zones

The groundwater depth of the desert riparian zone in the lower reaches of the Ugan River varies with the monitoring transect. The WG10 is the shallowest (2.54 m), WG7 is the deepest (9.48 m), WG1–4 and WG9 are between 4–5 m, and WG5–6 and WG8 are between 7–8 m (Figure 2). This shows that the spatial distribution of the water depth in the study area is heterogeneous.

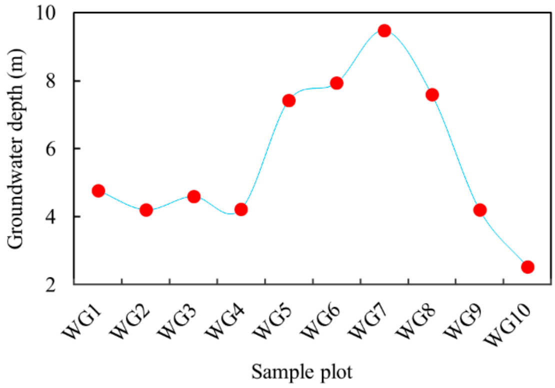

Figure 2. The groundwater level characteristics of 10 monitoring wells.

3.2. Species Composition and Diversity

Based on the investigation of the sample plots, 17 species of plants were found that, belonged to the following nine families: *Tamaricaceae*, *Labiatae*, *Chenopodiaceae*, *Gramineae*, *Leguminosae*, *Salicaceae*, *Compositae*, *Asclepiadaceae*, and *Tribulus terrestris*. Species diversity varied according to transect (Figure 3). Specifically, the Shannon–Weiner index changed in the range of 5.21–16.33%, with an average of 10%; the maximum value appeared in WG10 and the minimum value in WG7. The Simpson index changed in the range of 6.35–14.09%, with an average of 10%; the maximum value appeared in WG10. The Pielou index changed in the range of 6.39–12.44%, with an average of 10%; the maximum value appeared in WG4 and the minimum value in WG8.

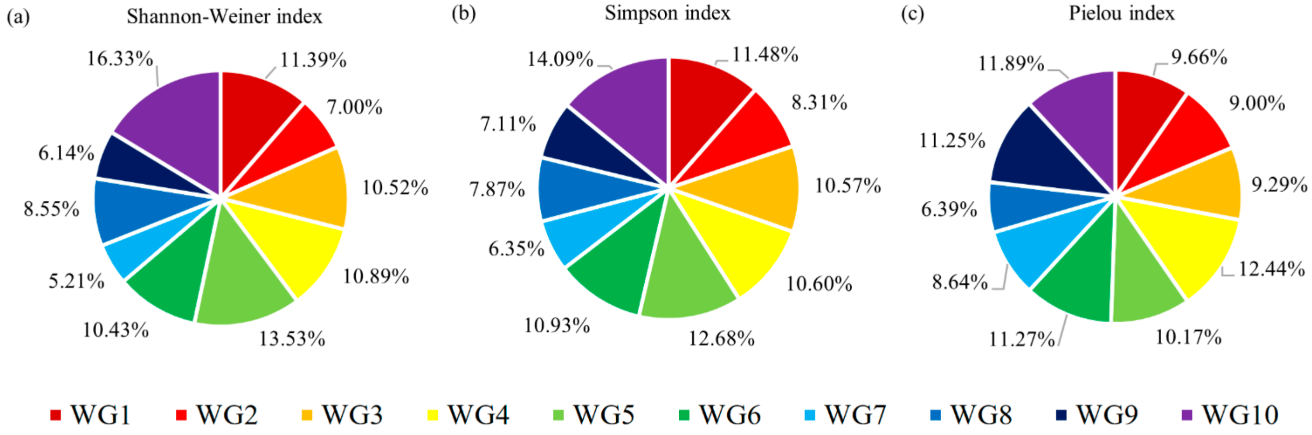

Figure 3. The (**a**–**c**) show the Shannon–Weiner index, Simpson index, and Pielou index characteristic of 10 monitoring wells, respectively.

3.3. Species Diversity Changes with Groundwater Depth

By analyzing the relationship between groundwater depth and species diversity, it was found that the Shannon–Weiner index of vegetation decreased gradually as the groundwater depth increased; herbaceous and woody plants also showed a downward trend (Figure 4a). It can be seen in Figure 4a that there are three obvious water level gradients in the distribution of plants, namely 2–4 m, 4–6 m, and 8 m. Of these, the 2–4 m woody plant diversity was found to be higher than the herbaceous plant diversity, while the sample plot distribution was found to be less. Further, the 4–6 m woody plant diversity was higher than the herbaceous plant diversity, and the sample plot distribution was somewhat notable. Finally, the woody plant diversity near 8 m was relatively higher than the herbaceous plant diversity, and the sample plot distribution was clearly notable.

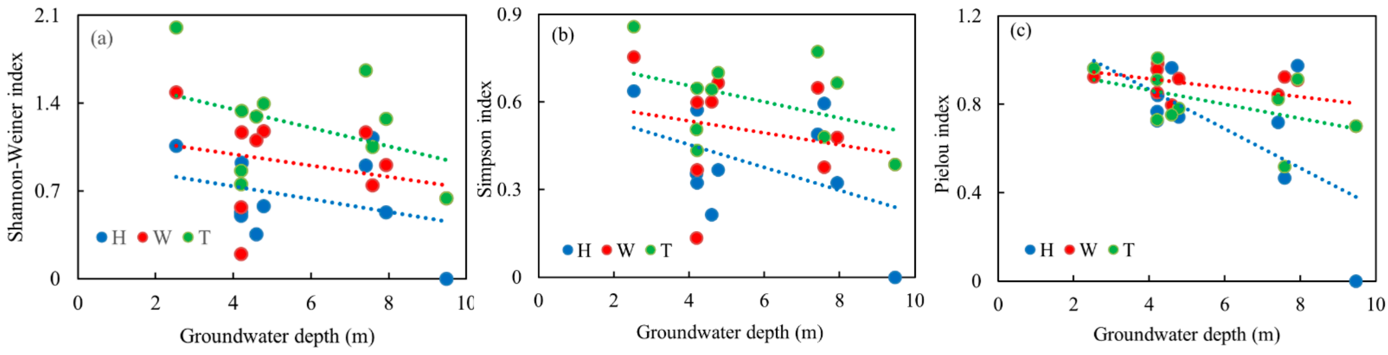

Figure 4. The (**a**–**c**) show the Shannon–Weiner index, Simpson index, and Pielou index characteristics with groundwater depth, respectively. and "H" refers to herbaceous plants, "W" refers to woody plants, and "T" (Total) refers to both herbaceous and woody plants.

Three points can be drawn from these findings: first, woody plants (arbors and shrubs) are the main plants in the desert riparian zone of the lower reaches of the Ugan River; second, the groundwater level is generally low—less than 4 m but higher than 10 m; and third, the drought tolerance of herbaceous plants may be lower than that of woody plants, which has higher requirements for water depth. The change trend of the Simpson index is similar to that of the Shannon–Weiner index (Figure 4b), i.e., plant diversity decreases as groundwater level decreases. The Pielou index indicated that the herbaceous plants decreased sharply with decreases in groundwater level, whereas the woody plants decreased only slightly (Figure 4c). In other words, the species diversity index and species richness index showed a downward trend when the groundwater depth increased. When the groundwater depth exceeded 9 m, only a few species (*Populus euphratica*) survived while species diversity was low. This shows that in the lower reaches of the Ugan River, groundwater is critical for maintaining the survival of plants, and the depth of the groundwater directly determines the growth and decline of plants.

3.4. Grey Correlation Analysis between Species Diversity Index and Groundwater Depth

In order to determine the influence of groundwater depth on the species diversity of a community, the grey correlation analysis method was used to calculate and rank the correlation degree of elements (Table 1). The data show that the correlation degree between groundwater depth and the species diversity index differs in various degrees. Specifically, the Margalef species richness index had the highest correlation with groundwater depth (0.70), whereas the Menhinick index had the lowest correlation degree (0.58). The correlation degrees between other species diversity indexes and groundwater depths were above 0.65 and rank in the following order: Margalef index > Simpson index > Pielou index >Patrick index > Shannon–Weiner index > Menhinick index.

Table 1. Correlation degree between species diversity index and groundwater depth.

Diversity Index	**Shannon–Weiner Index**	**Simpson Index**	**Margalef Index**	**Patrick Index**	**Menhinick Index**	**Pielou Index**
Correlation degree	0.65	0.67	0.70	0.66	0.58	0.67

3.5. Species Substitution Rate and Its Relationship with Groundwater Depth

The rate or degree of species substitution along environmental gradients is indicated by β diversity, which reflects environmental heterogeneity and species composition differences among regions [35]. The study revealed that the average substitution rates of community species in different riparian zones of the lower reaches of the Ugan River varied according to transect (Figure 5). Further, the results showed that the average substitution rate of species in WG4, WG6, and WG8 was higher, indicating that species composition difference was strong and habitat heterogeneity high. Meanwhile, the average substitution rate of species in other transects was relatively low, indicating that species composition difference was relatively weak, or habitat heterogeneity was comparatively low.

In addition, the average substitution rate of woody plants was significantly higher than that of herbaceous plants (except for WG8), indicating that woody plants had obvious differences in the community, while herbaceous plants were relatively consistent. In general, the change trend of β diversity of woody plants was similar to that of community species and had a strong impact on the change of community species, while in WG8, the difference was strongly affected by herbaceous plants.

The relationship between species substitution rate and groundwater depth is a single peak quadratic function. Within a certain range, decreases in groundwater level exhibited a rising trend followed by a falling trend. This trend suggests that suitable water depth can promote species substitution, but it will eventually inhibit species substitution due to the water level being too deep.

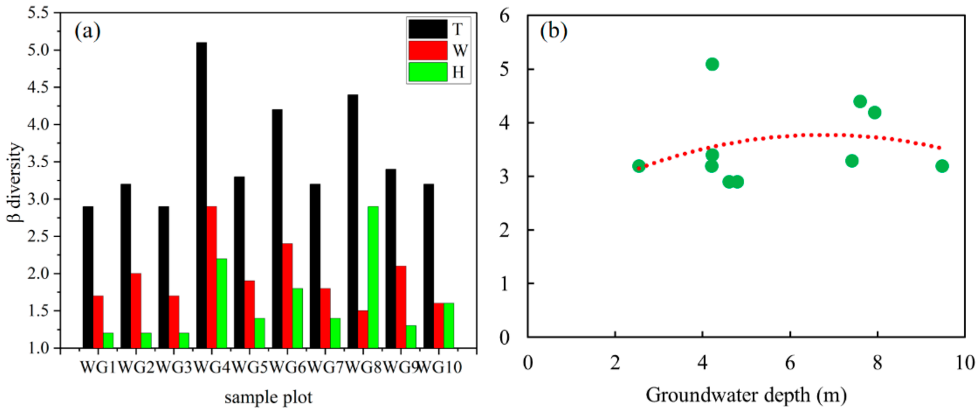

Figure 5. Spatial distribution of species replacement rate (**a**) and its relationship with groundwater (**b**). "H" refers to herbaceous plants, "W" refers to woody plants, and "T" (Total) refers to both herbaceous and woody plants.

3.6. Characteristics of Vegetation Coverage and Its Variation with Groundwater Depth

Vegetation coverage is a basic index for quantifying vegetation characteristics, and the coefficient of variation can reflect the dispersion degree of plant distribution. Generally, it can be divided into weak variability ($Cv < 0.1$), medium intensity variability ($0.1 < Cv < 1$), and strong variability ($Cv > 1$). The vegetation coverage in the study area varied with groundwater depth. For example, the vegetation coverage across the entire study region ranged from 13.33% to 67.28%, with an average of 33.58% and a coefficient of variation of 0.64. The coverage of woody plants ranged from 10.06% to 66.71%, with an average of 26.10% and a coefficient of variation of 0.69. The coverage of herbaceous plants ranged from 0 to 39.60%, with an average of 7.34% and a coefficient of variation of 1.69. From this, it is clear that the coverage of woody plants is higher than that of herbaceous plants, whereas the dispersion degree of herbaceous plants is higher than that of woody plants (Table 2), indicating strong variability.

Table 2. The characteristics of vegetation coverage.

Community Type	Min (%)	Max (%)	Mean (%)	Coefficient of Variation
H	0	39.60	7.34	1.69
W	10.06	66.71	26.10	0.69
T	13.33	67.28	33.58	0.64

The research findings also showed that herbaceous plants were more dispersed than woody plants and their stability was poor. As groundwater levels decreased, vegetation coverage likewise decreased, with herbaceous plants being very obviously subject to groundwater. The results of the current study revealed that when groundwater depth exceeded 8 m, coverage was reduced to 0, and that woody plants were less restricted by groundwater than herbaceous plants (Figure 6). The groundwater level in the plant community distribution area was mainly around 2 m, 4 m, and 8 m, and the response groundwater level of vegetation with higher coverage was 2–5 m, with high distribution of both herbaceous and woody plants.

3.7. Population Patterns of Dominant Species

The population spatial pattern of dominant species refers to the allocation or distribution of individuals in a population in horizontal space, which is the result of the comprehensive effects of population relationship, population characteristics, and environment. The dominant species of any plant community play a key role in maintaining community structure and function. Studying the spatial distribution pattern of dominant species helps to clarify the interaction process or dynamic succession characteristics between the plant community and the environment; it also reveals the restoration mechanisms of the population [38].

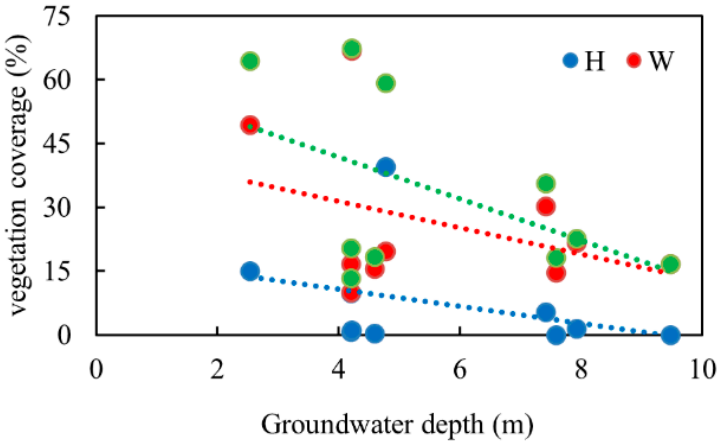

Figure 6. The variation of vegetation coverage of herbaceous plants, woody plants, and total plants with groundwater depth. "H" refers to herbaceous plants, "W" refers to woody plants, and "T" (Total) refers to both herbaceous and woody plants.

Through analysis of important values, it was found that *Tamarix chinensis*, *Hippophae rhamnoides*, *Halocnemum strobilaceum*, *Kareliniacaspia*, *Alhagi sparsifolia*, and *Populus euphratica* are dominant species in the desert riparian zone of the lower reaches of the Ugan River. Further analysis of the (C, t test), (m^*), (I), (PI), and (C_a) showed that these six species had aggregated distribution (Table 3) and passed the unilateral significance test of $t = 0.05$. This indicates that the dominant species of plants in the study area have the characteristics of aggregation and growing in patches. Therefore, the degraded vegetation can be gradually restored by way of point and surface (i.e., flowering in the center and spreading outward).

Table 3. Distribution pattern of dominant populations.

Species Name	Diffusion Coefficient Method	*t* Value	Mean Crowding Intensity	Clumping Index	Agglomerative Index	Cassie Index	Distribution Pattern
Tamarix chinensis	2.83	29.712	1.91	1.83	23.53	22.53	Aggregation distribution
Hippophae rhamnoides	1.32	5.186	0.44	0.32	3.70	2.70	Aggregation distribution
Halocnemum strobilaceum	1.35	5.666	0.41	0.35	6.89	5.89	Aggregation distribution
Kareliniacaspia	1.20	3.290	0.31	0.20	2.81	1.81	Aggregation distribution
Alhagi sparsifolia	1.24	3.867	0.40	0.24	2.48	1.48	Aggregation distribution
Populus euphratica	3.11	34.280	2.12	2.11	247.52	246.53	Aggregation distribution

4. Discussion

4.1. Characteristics of Plant Communities in the Study Area and Its Relationship with Groundwater Depth

Species diversity not only reflects the species composition, structure type, and stability of the community, but also maintains the operation of the ecosystem structure and function. Therefore, it is important to study plant community diversity to maintain the stable development and ecological balance of the community [7].

Tests conducted on desert riparian plants in the study area showed that the Shannon–Wiener index, Simpson index, and Pielou index all decreased as groundwater depth increased. The grey correlation analysis showed that the correlation degree between the species diversity index and groundwater depth was above 0.65 (except for the Menhnick index). This shows that the species diversity of the desert riparian zone is closely related to groundwater depth, and that groundwater has a crucial impact on plant survival and distribution. The finding is similar to the result of the study by Wang [39], in which the riparian species mainly relied on groundwater. Shi also indicated that groundwater depth affected the plasticity of morphological and physiological characteristics of *Populus euphratica* to varying degrees [40].

In the study region, herbaceous plants can only survive in a small range of groundwater depth, and their drought tolerance is weak. Compared with woody plants, herbaceous plants were shown to be more vulnerable to groundwater threats, resulting in lower diversity. Woody plants, on the other hand, can survive in a large range of groundwater depths and have strong drought tolerance, so they are the primary species maintaining the ecological balance of the region. When the groundwater depth was between 2 m and 4 m, the species diversity index was the largest. Shallow groundwater depth was helpful for maintaining greater growth rates and species health [41]. However, when the groundwater depth exceeded 4 m, the species diversity gradually decreased, because when the groundwater depth was too large, the water potential was low and the species that prefer wet conditions dieback [42]. When the groundwater depth was too shallow, it generally led to soil salinization, which is not conducive to plant growth. In cases where the groundwater depth was too deep, the amount of shallow-rooted plants were limited due to insufficient root pressure or lack of contact with water [43]. These findings suggest that groundwater depth should be maintained at 2–4 m in order to restore the degraded desert riparian vegetation in this area.

The average substitution rate of community species in the different riparian zones of the study area varied with transect. Moreover, the average substitution rate of woody plants was found to be significantly higher than that of herbaceous plants (except for WG8), which has a strong impact on species change of communities as well as the ecological balance of the region. As groundwater depth increased, the rate of species substitution initially increased and then decreased. This may be due to the decrease in groundwater level, with some shallow-rooted and drought-resistant plants becoming stressed. When this occurred, they were replaced by more deeply rooted and drought-tolerant plants, resulting in an increased substitution rate. In the future, if the groundwater level decreases, a large number of plants will disappear, and only some plants (*Tamarix chinensis* and *Populus euphratica*) will likely survive. When this occurs, there will be no replacement plants, which will lead to a gradual decline in the substitution rate and severe plant degradation.

Vegetation coverage is the basic index for quantifying the characteristics of vegetation, and the degradation of the ecological environment is reflected in this coverage. The present study indicated that in the lower reaches of the Ugan River, the vegetation coverage of the desert riparian zone differed according to groundwater depth. Further, it was found that the coverage of woody plants (26.10%) was higher than that of herbaceous plants (7.34%), indicating that herbaceous plants are more vulnerable to water resource threats than woody plants under drought conditions and that their stability is poor. This is because herbaceous plants are mostly annual or perennial and have shallow root distribution, whereas woody plants are perennial plants with deep root distribution characteristics. The response groundwater level of vegetation with larger coverage was 2–5 m, which indicates that the suitable groundwater depth range for vegetation growth in the study area was 2–5 m, which is very similar to the plant diversity results.

With the aggravated effects of climate change and the influence of human activities, the dominant plant populations in the area under study have become aggregated and mainly limited by groundwater. With the decrease in groundwater levels, the living environment of the vegetation has further deteriorated, and some non-xerophilic species have even disappeared, resulting in a large reduction in vegetation growth area. The distribution pattern of vegetation has also changed with the deterioration of habitat. Some of the remaining plants mainly rely on root sprouting or branch sprouting, so they all gather in the relatively good habitat area around the mother plant, and the aggregation intensity is high. This aggregation pattern is beneficial for improving the microenvironment of the community, increasing the competitiveness of the population, and enhancing the resistance of the population. It is an active ecological strategy for a population to adapt to the habitat conditions and continuously improve the environment for survival and development.

4.2. Degradation Mechanism Analysis

In the long-term growth process, plants form their own unique physiological and ecological functional characteristics (drought tolerance, saline alkali tolerance, heat resistance, etc.) [44]. The success rate of the affected plants under these adaptive characteristics determines their survival. The elimination of the less successful and the survival of the fittest are reflected, respectively, in the regression or development of the plants.

In the lower reaches of the Ugan River, the climate is dry, water resources are insufficient, and salinization is a serious problem. After a long period of natural selection, the arbors are mainly *Populus euphratica*; the shrubs are mainly *Tamarix chinensis*, *Hippophae rhamnoides*, *Halocnemum strobilaceum*, *Halostachys caspica*, *Kalidiu-m foliatum*, *Nitraria tangutorum* etc.; the semi-shrubs are mainly *Cynanchum auriculatum* and *Kochia prostrata*; and the herbaceous plants are mainly *Kareliniacaspia*, *Hexinia polydichotoma*, *Alhagi sparsifolia*, *Salsola ruthenica*, *Halogeton arachnoideus*, *Salsola collina*, *Aeluropus pungens*, *Phragmites communis*, etc. Some plants with certain resistance are primarily composed of *Swertia mussotii* and *Phragmites australis*. In a certain range of habitat conditions, these plants have the characteristics of drought tolerance, salt tolerance, and so on.

A few studies have pointed out that the drought tolerance of plants is likely to depend on the characteristics related to their hydraulic system [43], while salt tolerance is related to the characteristics of salt rejection, salt secretion, and dilute salt. Compared with the narrow range of water adaptability of herbaceous plants, arbors and shrubs adapt to the habitat with higher drought intensity and stronger vitality. This is because arbors and shrubs have deeper roots and thus a stronger ability to use water resources, which is also determined by their own physiological and ecological characteristics.

Plant survival is not only closely related to the physiological and ecological characteristics of plants, but is also affected by a variety of environmental factors (climate, salinity, nutrients, water, etc.) [45,46]. Water availability is crucial, especially in arid and semi-arid desert areas [31]. As noted earlier, plant diversity in the study area decreased as groundwater depth increased. Initially, some shallow-rooted and non-drought-tolerant herbaceous plants degraded and became apoptotic as the depth increased. With continued increases, however, even some deep-rooted and drought-tolerant plants will degenerate because they cannot bear long-term water shortage. These changes will have the effect of simplifying the plant community structure from diversification to unionization.

The main cause of plant degradation is water shortage, which may be due to a number of different factors summarized as the “source and sink” of water. As a water source, water vapor is insufficient in the study area. The Ugan River is located in a mid-latitude region of inland China, far away from the sea; it is also adjacent to the Taklimakan Desert to the south, which is surrounded by high mountains. These features further exacerbate the water vapor shortage.

Second, the Ugan River has a typical continental climate characterized by minimal precipitation and uneven annual precipitation distribution. This leads to a scarcity of surface runoff, resulting in the drying up of the downstream runoff. A third consideration is that the Ugan River is a mountain-sourced water body whose surface runoff mainly comes from glaciers, ice and snow melt water in the alpine zone, precipitation in the middle mountain forest zone, and bedrock fissure water in the low mountain zone [47]. However, the fifth IPCC Assessment report points out that the global climate has been in a warming stage over the past 100 years, and that the spatial and temporal distribution of water resources and precipitation patterns have changed due to the warming (IPCC, 2013). The snow area has also decreased, and glaciers have retreated, leading to a reduction in water reserves in the mountain areas. The end result of these changes is uncertainty in the water cycle system in the mountains and an increase in the variability of water resources in the downstream portion of the desert riparian zone.

Regarding the "sink" of water resources, radiation is strong, and evaporation is intensified under the natural conditions of the study zone. Furthermore, the scarce precipitation forms surface runoff that readily evaporates. Some studies have pointed out that precipitation of less than 13 mm in arid areas will be evaporated directly [5]. Moreover, the area of irrigated farmland in the region's oasis is the largest and most inefficient water structure in the Aksu region, causing heavy agricultural water consumption and a shortage of ecological water [22]. The heavy consumption means that there is no surface water available for natural vegetation.

At the same time, the increase in the population scale and human activities in the study area have further intensified water consumption. Specifically, in the upstream area, there has been a steady increase in both industry and domestic water consumption, and the construction of water conservancy facilities (reservoirs) has resulted in the cutoff of the river channel downstream. Meanwhile, in the downstream area, a large amount of groundwater has been exploited to compensate for the lack of surface water resources, resulting in a sharp decrease in groundwater levels and further aggravating the ecological degradation and the shortage of ecological water resources.

With these circumstances, it is clear that the lack of water sources and the increase in water dissipation are the main factors leading to vegetation degradation in the study area's desert riparian zone. In addition, water, as a medium, plays an important role in salt transmission and nutrient transport, which is the indirect embodiment of salt and nutrients affecting plant survival and growth.

5. Conclusions and Countermeasures

The spatial distribution of the groundwater depth in the study area is heterogeneous with WG1–4 and WG9 being between 4–5 m, WG5–8 more than 7 m, while WG10 is 2.54 m. Seventeen species of plants were found that, belonged to nine families and the dominant species of plants had characteristics of aggregated distribution. The maximum value of the Shannon–Weiner index (SWI) and Simpson index (SI) appeared in WG10 and the minimum value in WG7, while the maximum value of the Pielou index (PI) appeared in WG4 and the minimum value in WG8. The three indexes changed in the range of 5.21%–16.33% (SWI), 6.35%–14.09% (SI), 6.39%–12.44% (PI), respectively. The results also indicated that the vegetation coverage, Shannon–Wiener index, the Simpson index, and the Pielou index decreased as the groundwater depth increased. Furthermore, to promote the ecological balance and vegetation reconstruction, the relative optimal groundwater depth range should be maintained within 2 to 5 m so that the vegetation can grow well. and the degraded vegetation can gradually be restored using point and surface (i.e., flowering in the center and spreading to the surrounding areas). In addition to solving the ecological water crisis, the proper control of human activities is key.

Overall, the research determined that the degradation of vegetation in the study area is the result of the comprehensive action of several different factors, including: (1) the physiological and ecological characteristics of plants; (2) the influence of water factors; and (3) the intense water consumption (water shortage) caused by human activities, which results in ecological water shortages and ecological degradation in the desert riparian zone.

Based on the above findings, the following responses are suggested:

(1) Establish awareness and strengthen supervision: Cultivate people's awareness of the importance of water conservation. The population scale of the Ugan River Basin is large, and the growth rate is fast. If everyone living there does their best to conserve

water on a daily basis, these efforts will accumulate over time and translate to a considerable amount of water resources.

(2) Implement and monitor scientific policy: Monitoring is a key prerequisite for protecting the ecosystem. It is also an important basis for decision-making and is essential for the restoration and reconstruction of degraded ecosystems. Therefore, the intensity and frequency of monitoring vegetation and environmental factors should be increased in the study area.

(3) Develop a reasonable layout and a good addition and subtraction method: This approach requires properly controlling population size and growth rate, appropriately reducing the proportion of farmland, and improving the crop planting structure without endangering either food security or farmers' livelihoods. One strategy could involve abandoning farmland that is not suitable for farming, so as to change the planting concept of high-water consumption crops. In addition, the proportion of ecological water use should be appropriately increased, and the ecological water supply for the degraded vegetation implemented.

(4) Optimize industrial patterns and adjust the water consumption structure: Agriculture and industries characterized by high water consumption (e.g., the mining industry) could be replaced with secondary and tertiary industries requiring lower water consumption. This includes industries such as processing and tourism. The aim here is to transform the extensive (flood irrigation) water consumption structure to a more economical and efficient (drip irrigation) water structure to help mitigate the water resource crisis.

(5) Encourage people's involvement in the restoration process: Develop programs that encourage and enable people to help restore degraded and other ecologically vulnerable areas through enclosures, artificial replanting, floating seeds, seed bank activation, and other measures.

(6) Research and develop new types of plants: Use the modern rapid development of scientific and technological means to develop and cultivate plants with characteristics suitable for growth in the Ugan River Basin region, such as drought tolerance, salt tolerance, and so on.

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