

## Article

# Patterns of Diversity and Community Assembly and Their Environmental Explanation across Different Types of Shrublands in the Western Loess Plateau

Jinshi Xu <sup>1,2,\*</sup> , Han Dang <sup>2,3,4</sup>, Dechang Hu <sup>1</sup>, Ping Zhang <sup>1</sup> and Xiao Liu <sup>2,\*</sup>

<sup>1</sup> School of Life Sciences, Ludong University, Yantai 264025, China; hudch78@163.com (D.H.); ping.zh@163.com (P.Z.)

<sup>2</sup> School of Life Sciences, Northwest University, Xi'an 710069, China; danghan\_1102@163.com

<sup>3</sup> China ENFI Engineering Co., Ltd., Beijing 100038, China

<sup>4</sup> Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710058, China

\* Correspondence: suejineshek@163.com (J.X.); xiaoliu@nwu.edu.cn (X.L.)

**Abstract:** Shrubland is an important type of vegetation in the semi-arid region of the western Loess Plateau, and it is of great value to the maintenance of biodiversity and soil and water conservation. Equally, there may be significant differences in the level of diversity and the community assembly patterns across different types of shrublands (desert, alpine, and secondary shrublands). This study aimed to reveal the diversity and the community assembly patterns of different types of shrublands and the environmental explanations for these by using a taxonomic and phylogenetic analysis approach, as well as by considering soil and climate factors. The diversity level of the desert shrublands was low, and the habitats of the three types of shrubland were significantly different. Precipitation may be the main environmental factor driving the variation in and diversity of these types of shrubland. All three types of shrubland were strongly affected by environmental filtering and competitive exclusion, and their community assembly patterns were similar.

**Keywords:** succession stage; desert; alpine; secondary; community assembly



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## 1. Introduction

The Loess Plateau experiences the most severe soil erosion of any region in the world, contributing to 97% of the Yellow River's total sediment content every year [1]. Within it, the western region of the Loess Plateau experiences this more seriously due to its harsh habitat and the serious human interference, low vegetation coverage, and soil erosion present here [2]. Shrubland is the main vegetation type in the western region of the Loess Plateau, which is of great significance to ecological security and soil and water conservation in this region [3]. Therefore, a comparative study of the existing shrubland formation in the western region of the Loess Plateau can help us understand the ecological differences between different shrubland types, clarify the reasons for the formation of the corresponding shrubland communities and provide theoretical support for vegetation restoration and biodiversity protection in this ecologically fragile area [4].

Here, "shrubs" specifically refer to the desert shrubland that is distributed in arid (including extremely arid, arid, and semi-arid) areas with an average annual precipitation of less than 400 mm; the alpine shrubland that is distributed above the upper limit of the vertical distribution of forest; and the secondary shrubland that has formed as part of the community succession process due to high-intensity and large-scale human activities (such as the secondary shrubland communities formed after forest harvesting and the return of farmland to forest). In the western region of the Loess Plateau, these three types of typical desert, alpine, and secondary shrubland communities vary in their formation. Therefore, due to the different reasons for the formation of different types of shrublands, their diversity

levels and ecological processes are obviously different. Biodiversity is a good indicator that characterizes the relationship between plants and environmental conditions [5]. It is necessary to explore the formation and maintenance mechanisms of the diversity of the three types of shrubland, clarify the environmental causes of the formation of these communities, and then reveal the development rules of the community in the secondary succession sequence of the Loess Plateau [6]. These studies may judge the community succession outcomes as well. However, there are few relevant studies, and the mechanism of assembling different shrub communities has not yet been discussed.

The phylogeny of a community can be regarded as a “proxy” for the functional traits of species in the absence of data on their functional traits; that is, it is assumed that closely related species in a community have similar functional traits and can be filtered by their environment [7]. Distantly related species can also occupy different ecological niches to avoid the limitations posed by similarity [8]. Therefore, studying diversity and community assembly mechanisms using phylogenetic methods has some advantages, such as high sensitivity and strong ecological significance. Meanwhile, species diversity can directly reflect the taxonomic differences between coexisting species in a community, thus revealing the spatiotemporal variation in species composition [9,10]. Thus, studies on community diversity and its formation and maintenance mechanisms should take into account taxonomic and phylogenetic diversity to clarify the pattern of diversity within a community from wider perspectives [11].

Based on vegetation maps and literature records, this study took the shrublands of the Shaanxi, Gansu, and Ningxia provinces of China in the western Loess Plateau as the research object. The taxonomic diversity, phylogenetic diversity, and community assembly patterns of desert shrublands, alpine shrublands, and secondary shrublands were explored. The diversity of the three shrublands and the mechanisms of maintaining this diversity were combined with geographical, climatic, and soil factors to explore the environmental causes of the formation of different types of communities. Based on the above research, we tried to answer the following questions: (1) Do environmental factors affect the distribution of shrubland communities? Which environmental factors dominate in the formation of shrubland community diversity? (2) Are there differences in the diversity patterns and assembly mechanisms of different types of shrublands?

## 2. Materials and Methods

### 2.1. Study Area

The research area of this study is located in the western Loess Plateau, covering three provinces, Gansu, Shaanxi, and Ningxia, in China. There are many different geographical units in the study area, such as the Tengger Desert, the Mu Us Desert, the Helan Mountains, the Liupan Mountains, the Qinling Mountains, the Ziwuling Mountains, the Huanglong Mountains, the loess hilly and gully region, etc., with a complex topography and diverse landforms. The altitude range is 550~3700 m, the mean annual temperature is  $-5\sim 17\text{ }^{\circ}\text{C}$ , and the mean annual precipitation is 130~1000 mm (Tables 1 and A1). A total of 52 shrub types were selected for this study, including 24 desert shrub types, 12 alpine shrub types, and 18 secondary shrub types. The sites sampled in this study were selected to investigate the most typical areas of each type. The specific shrub types and study sites are shown in Table 1. In our study, we selected shrubland communities with typical single dominant species for analysis to determine whether the community type was alpine, desert, or secondary shrubland. If the dominant species belonged to typical alpine species (flora recorded as only distributed in alpine environments), the shrubland was defined as alpine shrubland. Where the dominant species were typical desert species (e.g., those belonging to the Amaranthaceae or Zygophyllaceae or those whose flora was clearly recorded as growing in deserts), the shrubland was defined as desert shrubland. The remaining types of shrubland, especially non-zonal vegetation, were defined as secondary shrubland.

Table 1. Site information.

Community Type	Site Code	Dominant Species	Location	Latitude/°N	Longitude/°E	Elevation/m
Desert shrubland	DNRS	<i>Reaumuria songarica</i> (Pall.) Maxim.	Tongxin, Ningxia	36.915375	105.810581	1544
	DNAC	<i>Asterothamnus centralasiaticus</i> Novopokr.	Tongxin, Ningxia	36.915222	105.810589	1530
	DNCJ	<i>Caragana jubata</i> (Pall.) Poir.	Wuzhong, Ningxia	36.719008	105.540622	1779
	DNSP	<i>Caroxylon passerinum</i> (Bunge) Akhani and Roalson	Zhongning, Ningxia	36.999789	105.257414	1761
	DNOA	<i>Oxytropis aciphylla</i> Ledeb.	Zhongning, Ningxia	36.999381	105.258114	1780
	DNCT	<i>Caragana tibetica</i> Kom.	Zhongning, Ningxia	36.999097	105.257942	1784
	DNAO	<i>Artemisia ordosica</i> Krasch.	Zhongwei, Ningxia	37.448169	106.173331	1316
	DNKG	<i>Kalidium gracile</i> Fenzl	Tongxin, Ningxia	37.437297	106.449808	1313
	DNNT	<i>Nitraria tangutorum</i> Bobr.	Tongxin, Ningxia	37.437444	106.448036	1320
	DNAM	<i>Prunus mongolica</i> (Maxim.) Ricker	Helan, Ningxia	38.609011	105.927033	1591
	DNLO	<i>Leptodermis ordosica</i> H. C. Fu et E. W. Ma	Helan, Ningxia	38.609169	105.927208	1621
	DNEL	<i>Ephedra rhytidosperra</i> Pachomova	Helan, Ningxia	38.606356	105.928050	1655
	DNCK	<i>Caragana korshinskii</i> Kom.	Zhongning, Ningxia	39.348111	105.634903	1290
	DNMM	<i>Ammopiptanthus mongolicus</i> (Maxim. ex Kom.) Cheng f.	Shizuishan, Ningxia	39.405397	106.729878	1097
	DGAB	<i>Anabasis brevifolia</i> C. A. Mey.	Jingtai, Gansu	37.363667	104.137900	1592
	DGSX	<i>Zygophyllum xanthoxylum</i> (Bunge) Maxim.	Jingtai, Gansu	37.374603	104.163269	1614
	DGNS	<i>Nitraria sibirica</i> Pall.	Jingtai, Gansu	37.375506	104.159800	1613
	DGCM	<i>Calligonum mongolicum</i> Turcz.	Wuwei, Gansu	38.443858	102.932236	1388
	DGEP	<i>Ephedra przewalskii</i> Stapf	Minqin, Gansu	38.566175	102.845219	1373
	DGNP	<i>Nitraria sphaerocarpa</i> Maxim.	Yongchang, Gansu	38.729933	102.334781	1372
DGNR	<i>Nitraria roborowskii</i> Kom.	Yongchang, Gansu	38.758275	102.350600	1348	
DGTC	<i>Tamarix chinensis</i> Lour.	Minqin, Gansu	38.203958	102.765156	1443	
DGHA	<i>Haloxylon ammodendron</i> (C. A. Mey.) Bunge	Minqin, Gansu	38.204842	102.766300	1449	
DSSC	<i>Salix cheilophila</i> Schneid.	Shenmu, Shaanxi	38.787222	110.243056	1223	
Alpine shrubland	AGRC	<i>Rhododendron capitatum</i> Maxim	Tianzhu, Gansu	36.959111	102.816169	3326
	AGPF	<i>Dasiphora fruticosa</i> (L.) Rydb.	Tianzhu, Gansu	36.958769	102.816864	3313
	AGRP	<i>Rhododendron przewalskii</i> Maxim.	Tianzhu, Gansu	36.955908	102.828906	3320
	AGSG	<i>Salix gilashanica</i> C. Wang et P. Y. Fu	Tianzhu, Gansu	36.944772	102.831228	3244
	AGBT	<i>Berberis thunbergii</i> DC.	Tianzhu, Gansu	36.945528	102.831958	3251
	AGSA	<i>Spiraea alpina</i> Pall.	Tianzhu, Gansu	36.945497	102.831997	3249
	AGSC	<i>Salix cupularis</i> Rehd.	Gannan, Gansu	33.841131	104.264250	2739
	AGSS	<i>Sorbaria sorbifolia</i> (L.) A. Br.	Gannan, Gansu	33.840844	104.262869	2809
	AGHR	<i>Hippophae rhamnoides</i> L.	Gannan, Gansu	33.841431	104.264633	2740
	AGPP	<i>Dasiphora parvifolia</i> (Fisch. ex Lehm.) Juz.	Lintan, Gansu	34.757606	103.609528	3187
	AGBK	<i>Berberis kansuensis</i> Schneid.	Kangle, Gansu	34.939761	103.752256	3212
	AGSQ	<i>Juniperus squamata</i> Buchanan-Hamilton ex D. Don	Kangle, Gansu	34.939764	103.752258	3300

Table 1. Cont.

Community Type	Site Code	Dominant Species	Location	Latitude/°N	Longitude/°E	Elevation/m
Secondary shrubland	SSOD	<i>Ostryopsis davidiana</i> Decaisne	Yaozhou, Shaanxi	35.152300	108.836944	1150
	SSVN	<i>Vitex negundo</i> var. <i>heterophylla</i> (Franch.) Rehd.	Xunyi, Shaanxi	35.156047	108.281111	1138
	SSRH	<i>Rosa hugonis</i> Hemsl.	Chengcheng, Shaanxi	35.185314	109.868611	1160
	SSSV	<i>Sophora davidii</i> (Franch.) Skeels	Chengcheng, Shaanxi	35.070753	109.869722	1000
	SSSO	<i>Syringa oblata</i> Lindl.	Huanglong, Shaanxi	35.583330	109.816670	1212
	SSZJ	<i>Ziziphus jujuba</i> var. <i>spinosa</i> (Bunge) Hu ex H.F.Chow.	Fuping, Shaanxi	35.062778	109.278611	947
	SSRP	<i>Rubus piluliferus</i> Focke	Chang'an, Shaanxi	34.042500	108.836667	566
	SSGB	<i>Grewia biloba</i> G. Don	Chang'an, Shaanxi	34.042222	108.836667	650
	SSLF	<i>Lespedeza thunbergii</i> subsp. <i>formosa</i> (Vogel) H. Ohashi	Chang'an, Shaanxi	34.042222	108.836944	687
	SSCG	<i>Celastrus gemmatus</i> Loes.	Zhouzhi, Shaanxi	34.058333	108.281111	606
	SSCN	<i>Coriaria nepalensis</i> Wall.	Shanyang, Shaanxi	33.520278	109.869722	739
	SSMA	<i>Myrsine africana</i> L.	Baihe, Shaanxi	32.859167	110.010833	249
	SSFS	<i>Forsythia suspensa</i> (Thunb.) Vahl	Baihe, Shaanxi	32.859167	110.011111	295
	SSSS	<i>Spiraea sericea</i> Turcz.	Baihe, Shaanxi	32.846944	110.009444	344
	SSLG	<i>Lindera glauca</i> (Siebold and Zucc.) Blume	Nanzheng, Shaanxi	32.591667	107.157222	891
	SSPP	<i>Pittosporum podocarpum</i> Gagnep.	Nanzheng, Shaanxi	32.593611	107.155000	858
	SSCC	<i>Cotinus coggygria</i> Scop.	Fengxian, Shaanxi	34.169419	106.773733	1250
SSQB	<i>Quercus baronii</i> Skan	Chenggu, Shaanxi	32.855461	107.213786	682	

## 2.2. Investigation Methods

From 2018 to 2020, a field survey was conducted during the plant growth period from July to August, a time when the leaves of the plants are already mature and capable of reaching the maximum photosynthetic rate. In order to minimize differences between different shrubland groups being caused by different sampling times, the sampling time was unified, and the sampling was concentrated in July–August of the same year. In 52 plots, three quadrats were arranged at sites with typical vegetation. The distribution area of the shrublands where the quadrats were located was no less than 25 × 25 m. The quadrats were 5 × 5 m, and the radius of the distribution of the three quadrats did not exceed 250 m. The geographical factors, such as latitude and longitude, elevation, slope, and slope direction, of each quadrat were recorded. The identified name, abundance, and coverage of the shrub species in the quadrat were recorded. For further analysis, species from the three quadrats were aggregated by plot. The actual survey area of each plot was 75 m<sup>2</sup>. A total of 191 shrub species were counted in the survey.

## 2.3. Environmental Factor Data

Geographical factors were recorded in the field survey. In addition, at least 3 points were selected along the diagonal of each 5 × 5 m quadrat. Then, the undecomposed and semi-decomposed litter layers were removed, and 0–20 cm soil samples were collected for each quadrat, mixed, and put into self-sealing bags. A total of 9 mixed soil samples were

taken from each quadrat. These samples were brought back to the laboratory for analysis of the physicochemical properties of the soil. The soil's pH and organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) contents were determined using standard methods [12]. The average value was taken as representative data on the soil properties of the whole quadrat.

According to the longitude and latitude information, a  $1 \times 1$  km grid map depicting the climatic factors in the region was taken from the WorldClim database (<http://www.worldclim.org/>, accessed on 15 December 2022). As supported by previous studies, this study selected mean annual temperature (MAT) and mean annual precipitation (MAP) as the environmental factors for analysis [13]. The above data were obtained using the raster package in R 4.1.2 software (R core team, San Diego, CA, USA).

#### 2.4. Data Analysis

In order to investigate whether similar types of shrubland have consistent preferences in terms of the habitats selected, principal component analysis (PCA) was used to treat the environmental factors of each community to identify the differences in habitat between different types of shrublands. The PCA and mapping were performed in Canoco 4.5 software (Wageningen UR, Wageningen, The Netherlands).

To analyze the diversity patterns of different shrubland communities, species richness and the Shannon–Wiener index were selected as the species diversity indexes in this study [14], and Faith's PD (namely the evolutionary branch length of all species in the community [15]) was selected as an indicator of the phylogenetic diversity.

Before phylogenetic analysis, it is necessary to construct a suitable phylogenetic supertree to reach accurate conclusions. In this study, to avoid false positive results being caused by an excessively large pool of species, species lists of desert shrubs, alpine shrubs, and secondary shrubs were selected to construct species pools for desert, alpine, and secondary shrubs. Then, phylogenetic trees of the three different types of communities were constructed based on these data. The phylogenetic database of species reported by Zanne [16] was used for the phylogenetic tree construction to assign evolutionary branch lengths. Construction of the phylogenetic trees was carried out in the "phylocomr" package in R 4.1.2 software. The species richness and Shannon–Wiener index were calculated using the "vegan" package in R 4.1.2 software. Faith's PD was calculated using the "phylo" package in R 4.1.2.

In order to clarify the formation and maintenance mechanisms of diversity, the net relatedness index (NRI) was the factor used to describe the phylogenetic structure. The specific calculation method of the NRI is as follows:

$$\text{NRI}_S = -1 \times \frac{\text{MPD}_S - \text{MPD}_{\text{rnds}}}{\text{sd}(\text{MPD}_{\text{rnds}})}$$

where MPD is the mean lineage distance between species in a quadrat [17]. The corner label S represents the actual observed value, and "rnds" represents the random simulation value of the software. When the  $\text{NRI} > 0$ , the phylogeny of the community shows aggregation, while at an  $\text{NRI} < 0$ , the phylogeny shows divergence; if the  $\text{NRI}/\text{NTI} = 0$ , there is random phylogenetic relation in the community [18]. The aggregation and divergence in the phylogeny can explain the key processes that influence community assembly and thus elucidate the mechanisms that maintain the diversity of the community. The NRI calculations were performed in the "COMSTRUCT" module in Phylocom 3.0 software (Webb et al., Cambridge, MA, USA). The diversity and phylogenetic structure of different types of shrubs were compared using ANOVA. The ANOVA was conducted in Statistica 9.0 software (StatSoft Inc., Tulsa, OK, USA). Multiple comparison box diagrams were produced in Origin 8.5 Pro (OriginLab Co., Studio City, CA, USA).

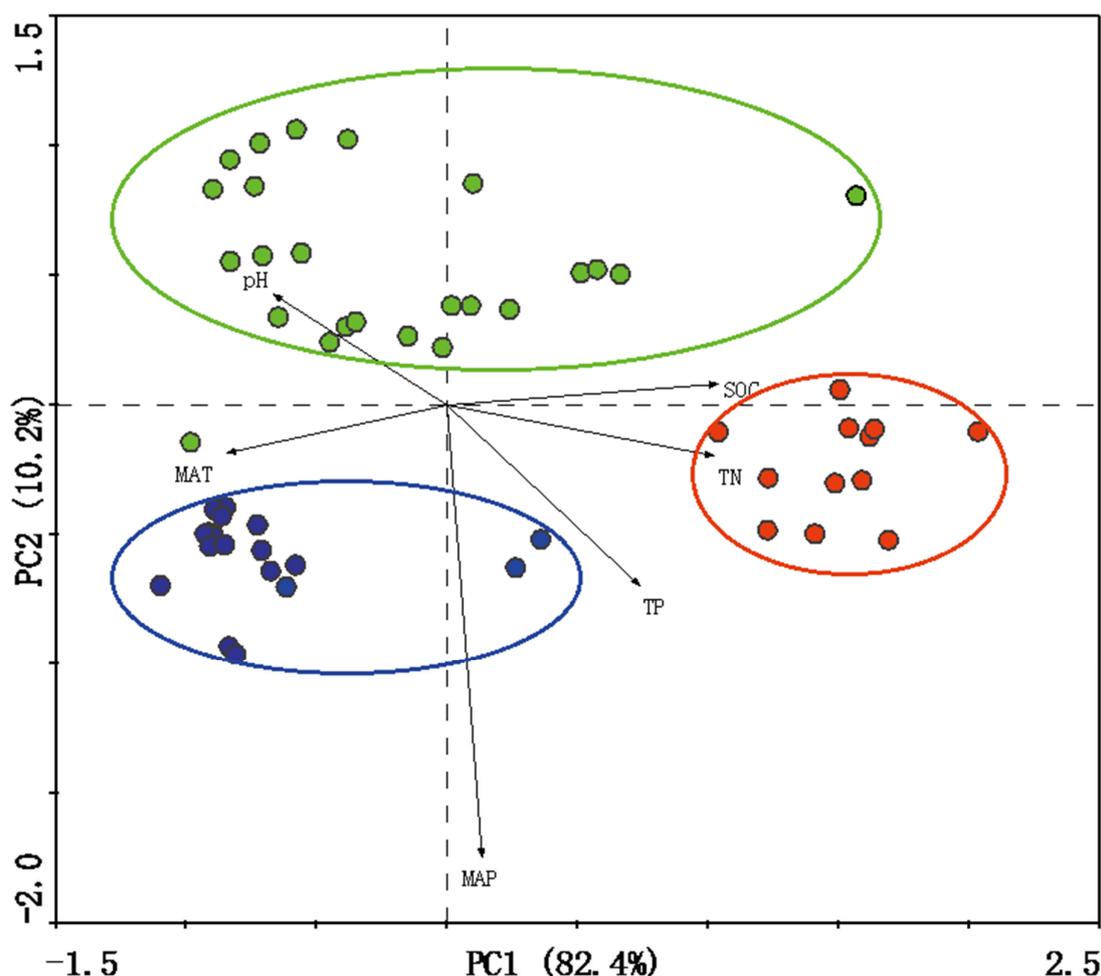
To clarify whether environmental factors influence the diversity and community assembly between different communities, Pearson analysis was used to explore the relationship between different environmental factors and the diversity, phylogenetic structure,

and diversity index. Then, MAP was selected as the main influencing factor based on this method. The diversity and phylogenetic structure data were linearly fitted to the MAP gradient. The Pearson correlation analysis was performed in SPSS 19.0 software (IBM, Armonk, NY, USA). The linear fitting and mapping were carried out in Origin 8.5 Pro.

### 3. Results

#### 3.1. Differences between Environmental Factors among Different Types of Shrublands

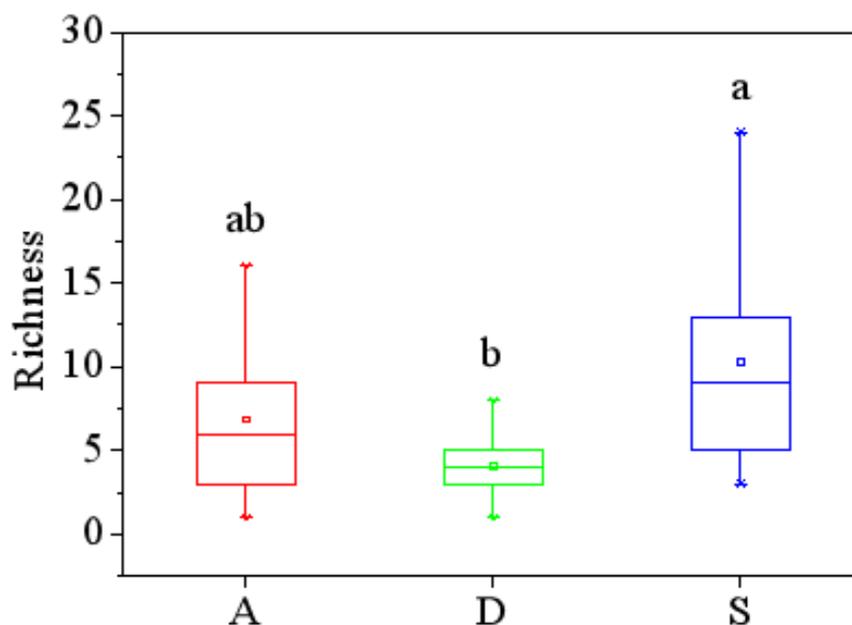
In this study, the climate factors and soil factors of different types of shrublands were all involved in the principal component analysis. The results showed that principal component axes 1 and 2 can explain 92.6% of the total variation in the environmental factors (of which the PC1 axis can explain 82.4% and the PC2 axis can explain 10.2%; see Figure 1). In the PCA, the distribution range of the desert, alpine, and secondary shrublands was clear, indicating that the different types of shrublands had obvious environmental differences. The different types of shrublands were separated by the PC2 axis, which was mainly related to MAP. Meanwhile, the alpine shrublands and secondary shrublands were separated by the PC1 axis as well, which was related to the MAT, SOC, TN, etc., indicating that these environmental factors may be the reasons behind the colonization and growth of different types of shrublands.



**Figure 1.** The PCA analysis of different types of shrublands. Red circles refer to alpine shrublands, green circles refer to desert shrublands, and blue circles refer to secondary shrublands. The ellipses represent aggregations of samples.

### 3.2. Community Assembly Patterns of Different Types of Shrublands

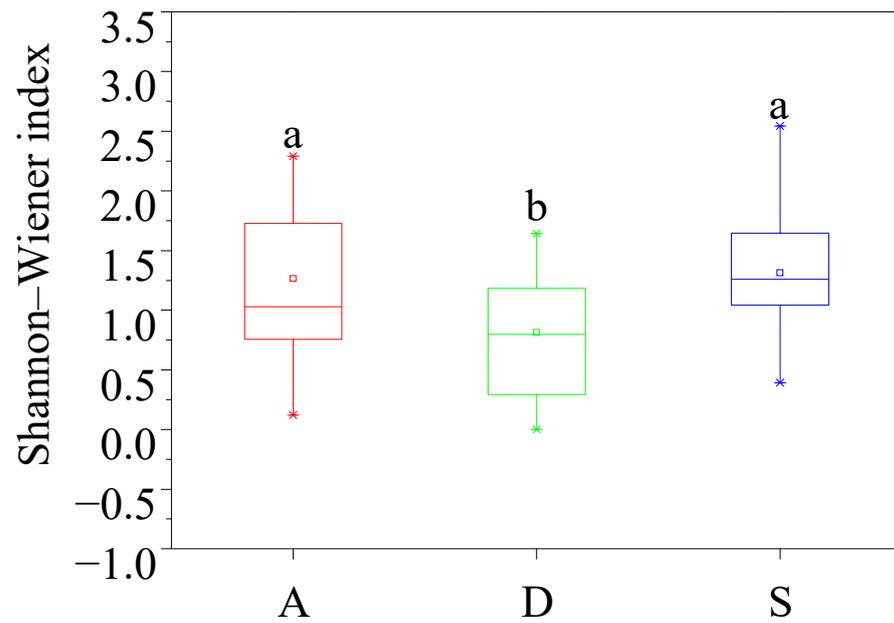
Pearson analysis showed that the species richness was highly correlated with the Shannon–Wiener index (Pearson = 0.859,  $p \approx 0$ ). Meanwhile, the species richness and phylogenetic diversity (Pearson = 0.964,  $p \approx 0$ ) and the Shannon–Wiener index and phylogenetic diversity (Pearson = 0.838,  $p \approx 0$ ) showed significant correlations as well. The results showed that the variation patterns of several diversity indexes were consistent in different types of shrublands. In terms of taxonomic diversity, the species richness and the Shannon–Wiener index of the desert shrubland were the lowest, while there was no significant difference in taxonomic diversity between the alpine shrubland and secondary shrubland species (Figures 2 and 3). The pattern in the phylogenetic diversity was similar to that in the taxonomic diversity. The phylogenetic diversity (PD) of the desert shrublands was significantly lower than that of the alpine shrublands and secondary shrublands (Figure 4). However, a comparison of the phylogenetic structure of the three types of shrub showed that there was no significant difference between the NRIs of the different types of shrublands, and the NRI of most communities was  $> 0$ , with no significant variation from 0 (Figure 5).



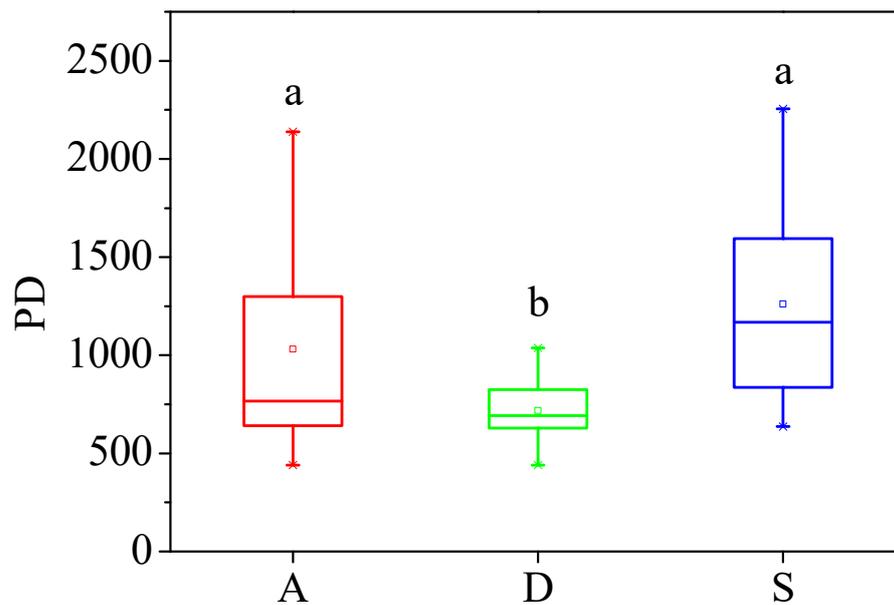
**Figure 2.** The richness of different types of shrublands. Different letters indicate significant differences. A refers to alpine shrublands, D refers to desert shrublands, and S refers to secondary shrublands.

### 3.3. Diversity Patterns among Different Types of Shrublands along the Precipitation Gradient

The Pearson analysis showed that there was no significant correlation between the soil factors and the taxonomic diversity, phylogenetic diversity, and phylogenetic structure. Among the climatic factors, the mean annual precipitation (MAP) was related to the taxonomic and phylogenetic diversity but not to the phylogenetic structure. Therefore, this study further discussed the rules of the variation in diversity among different types of shrublands along the MAP gradient. The results showed that the different types of shrublands had an obvious distribution range along the MAP gradient. The desert shrubland was only distributed where the MAP was  $< 450$  mm, the alpine shrubland experienced a MAP between 470 and 630 mm, and the secondary shrubland relied on a MAP between 500 and 1000 mm. In addition, the taxonomic diversity and phylogenetic diversity increased with an increase in precipitation (Figures 6–8).

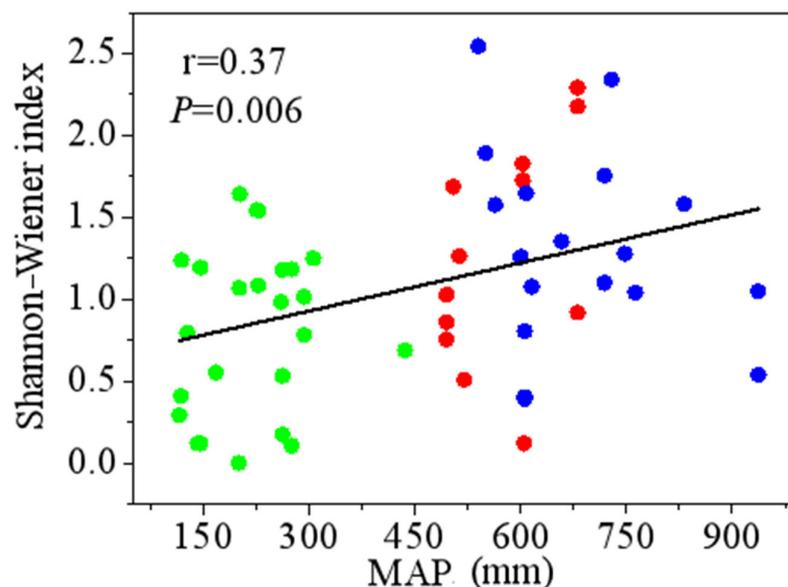


**Figure 3.** The Shannon–Wiener index of different types of shrublands. Different letters indicate significant differences. A refers to alpine shrublands, D refers to desert shrublands, and S refers to secondary shrublands.

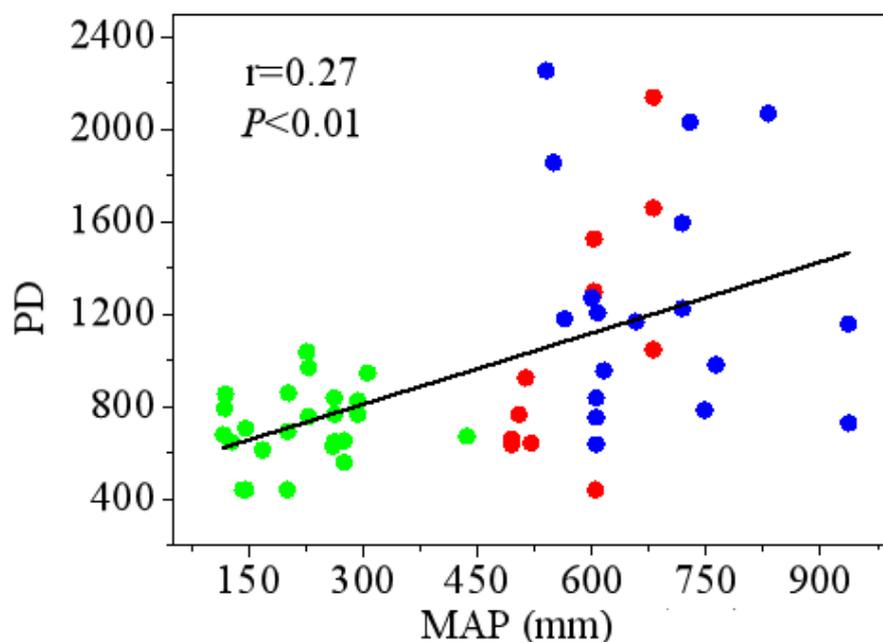


**Figure 4.** The phylogenetic diversity (PD) of different types of shrublands. Different letters indicate significant differences. A refers to alpine shrublands, D refers to desert shrublands, and S refers to secondary shrublands.





**Figure 7.** The Shannon–Wiener index of shrubland community along mean annual precipitation (MAP) gradient across different types of shrublands. The green circles represent desert shrublands, the red circles represent alpine shrublands, and the blue circles represent secondary shrublands, while the black line represents line fitting.



**Figure 8.** The phylogenetic diversity (PD) of shrubland community along mean annual precipitation (MAP) gradient across different types of shrublands. The green circles represent desert shrublands, the red circles represent alpine shrublands, and the blue circles represent secondary shrublands, while the black line represents line fitting.

#### 4. Discussion

##### 4.1. Variation in Diversity among Different Types of Shrublands

In this study, the taxonomic diversity and phylogenetic diversity among different types of shrublands showed a consistent pattern, and the species richness, Shannon–Weiner index, and Faith’s PD were highly correlated. These results are similar to those of previous studies [19], indicating that the selected indexes of taxonomic and phylogenetic diversity are appropriate.

Previous studies have found that with the progression of community succession, the community diversity may first increase and then decrease, and the inflection point appears at the shrub stage [20]. In one particular study, the secondary shrubland emerged due to the secondary succession sequence after being disturbed by humans, and there was not a climax community at the site, as it had a tendency toward forward succession [21]. Therefore, the diversity level of secondary shrublands may be high. In addition, due to the influence of human activities, more species closely related to human activities and even exotic species may be introduced into the secondary shrub, thus further increasing the diversity level of the secondary shrublands. In this study, it was also found that the diversity of the secondary shrublands at the taxonomic and phylogenetic levels was higher than that of the other shrublands, which can also confirm the previous hypothesis.

In this study, the taxonomic and phylogenetic diversity of the desert shrublands was significantly lower than that of the alpine shrublands and secondary shrublands. The habitats of desert shrublands are harsh, with many stress conditions (drought, high temperatures in summer, low temperatures in winter, high soil salinity, and low soil nutrients). Therefore, desert shrubland areas provide an ecological niche that is significantly less readily available than other shrubland areas of the same size. The high level of environmental filtering and interspecific niche competition in desert shrublands results in a significant decrease in the diversity level [22].

#### *4.2. Precipitation Leads to Colonization and Diversity Differences in Different Types of Shrublands*

The core argument of community ecology is to explore the relationship between the environment and community assembly [23]. Previous studies have found that the diversity level of a community is related to its local habitat. Factors such as the terrain, moisture and nutrients in the soil, and heat may affect the diversity level of a community [24–27]. However, in this study, the topographic factors (slope, aspect, elevation, etc.; see Table A2) were not related to the diversity level of the community, which was similar to the results of another study in this region [22], indicating that the topographic factors in the Loess Plateau region were not the main reasons for changes in the diversity level within the community. Although there were significant differences between the mean annual temperature of different places in this study (Table A1), there was no significant change trend in the community diversity pattern along the MAT gradient, and MAT did not seem to be related to the community assembly pattern. This result is different from previous studies [28,29], but other studies have shown that the levels and formation mechanisms of community diversity in alpine regions are not related to environmental factors such as heat [30]. In this study, the habitats of the three types of communities were all stressed by various conditions (such as drought, low temperature, nutrient deficiency, disturbance, etc.), and temperature may no longer be the main limiting factor leading to community changes. Similarly, although the nutrient gradient in the soil may also be the cause of community differences in this study (in the PCA analysis, three different types of communities could be separated by the PC1 and PC2 axes, and PC1 was closely related to soil indexes such as TOC and TN), a single soil factor could not explain the differences in the diversity levels.

In this study, MAP was the only environmental factor associated with changes in diversity levels. Previous studies have shown that differences in water availability can drive differences in diversity [31]. An increase in precipitation can lead to an increase in the woody species diversity in this study area and is a major factor leading to changes in community diversity levels [11]. The results of this study confirm the above conclusions. This indicates that water is still the main factor that limits the formation of shrub communities in the western part of the Loess Plateau.

It should be pointed out that in this study area, different types of shrublands showed obvious differences in the MAP gradient, especially for the desert shrublands, which grow in their entirety in the area with a MAP < 450 mm. Although there was no obvious boundary between the alpine shrubland and secondary shrubland along the MAP gradient, the amplitude of variation in the MAP of the secondary shrubland was higher than that of

the alpine shrubland, and the MAP level of certain shrubland sites was higher (>800 mm). This indicates that the alpine shrublands have a clear range of suitable precipitation, and their habitat is more consistent; that is, alpine shrubland communities are formed under specific precipitation conditions (the alpine shrubland community is the climax community). Secondary shrubland is a mid-successional community formed by human activities, and the range of variation in the MAP in its habitat is large; however, the successional outcome of secondary shrubland is inconsistent under different MAP values, and the climax community in the late-successional period may be determined by the type of zonal vegetation in the area. Therefore, a difference in precipitation can determine the type of shrubland formed in the western region of the Loess Plateau and can affect the diversity level of shrubland communities.

Interestingly, for the same type of shrubland, diversity did not show a change trend with MAP. However, this trend appeared when the three shrubland types were brought together (Figures 6–8). In fact, this phenomenon has been mentioned in a study of ecological processes at the local and regional scales [25]. In this study, because different types of shrublands have relatively similar combinations of environmental factors, their geographical distribution areas may also be relatively concentrated. We can assume that different types of shrublands are distributed in different areas. Due to differences in the ecological processes at the local to regional scales, different results will appear when considering the diversity of all types of shrubland across MAP gradients at the regional scale.

#### *4.3. The Assembly Process of Different Types of Shrubland Communities Is Similar*

Exploring and revealing the spatial patterns and maintenance mechanisms of biodiversity is a hot topic in ecology and biogeography [32]. In this study, the phylogenetic structures of the different types of shrublands were similar, indicating that shrubland communities whose formation had different causes in the western region of the Loess Plateau may have been affected by similar assembly processes. In this region, due to the harshness of the habitat, some species will have been excluded by environmental filtering during the assembly process [33]. The selected species may have similar traits, and the interspecific competition may be more intense. However, due to the limitations of the natural conditions in the region, the available niche within the community is limited, which may further exacerbate the degree of interspecific competition. In this study, the three types of communities all showed a weak pattern of phylogenetic convergence, but there was no significant difference from the null model, indicating that the shrubland communities may have been superimposed by environmental filtering and similarity limitations, which masked the independent influence of two opposite ecological processes on community formation and maintenance [34].

It should be noted in particular that in this study, species pools of different sizes were constructed when the phylogenetic structure was analyzed for the three different types of shrublands. The species pools of the three types of shrubland were the sum total shrub species in the community of that type. In previous studies, selecting species pools of different sizes had a great impact on the phylogenetic structure of a region [25]. In general, a species pool should be constructed according to all species and potential species in the study area. However, the three types of shrubland in this study have significant environmental differences (the PCA analysis showed that the three types of shrubland have obvious environmental differences), and the selection of a larger regional species pool will inevitably exaggerate the role of many species that are unlikely to appear in certain types of shrubland, resulting in a convergence pattern when calculating the phylogenetic structure that is inconsistent with reality. Therefore, in this study, only species that had appeared in the specific type of shrubland were selected for constructing the phylogenetic supertree. Relatively speaking, the selection of smaller supertrees may reduce the detection sensitivity of the patterns of phylogenetic convergence, further resulting in most of the communities in this study exhibiting insignificant convergence or even random community assembly patterns.

## 5. Conclusions

This study combined the diversity levels and phylogenetic structures of desert, alpine, and secondary shrublands in the western region of the Loess Plateau with the environmental factors affecting these communities to explore the effect of the former on the latter. It was found that the environmental factors in different types of shrubland communities were significantly different, and the diversity level of the desert shrublands was significantly lower than that of the alpine and secondary shrublands. The precipitation gradient can distinguish different types of shrublands and seemingly influences their diversity levels. In the western part of the Loess Plateau, the community assembly mechanism of different types of shrublands is similar, and they are all affected by higher levels of environmental filtering and competitive exclusion processes.

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**Data Availability Statement:** The original contributions presented in this study are included in the article; further inquiries can be directed to the corresponding authors.

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**Conflicts of Interest:** Han Dang was employed by the China ENFI Engineering Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The China ENFI Engineering Co., Ltd. had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## Appendix A

**Table A1.** Climate and soil environment information of the sampling sites.

Shrubland Type	Mean Annual Temperature (MAT)/°C	Mean Annual Precipitation (MAP)/mm	Soil Organic Carbon (SOC)/mg·g <sup>-1</sup>	Soil Total Nitrogen (TN)/mg·g <sup>-1</sup>	Soil Total Phosphorus (TP)/mg·g <sup>-1</sup>	pH of Soil
DNRS	8.3	293.0	6.6045	0.5865	0.3806	7.7956
DNAC	8.3	293.0	3.3325	0.2718	0.3627	7.6611
DNCJ	7.4	306.0	8.1056	0.7767	0.6586	8.3144
DNSP	7.4	262.0	9.2582	0.7091	0.5326	8.3078
DNOA	7.4	262.0	10.5879	0.8566	0.5192	8.0156
DNCT	7.4	262.0	13.2980	1.3253	0.5653	8.1833
DNAO	8.6	260.0	2.0243	0.1570	0.2307	8.8378
DNKG	8.6	275.0	3.9658	0.3274	0.4160	8.5856
DNNT	8.6	275.0	4.4528	0.3397	0.2926	8.7189
DNAM	6.7	228.0	21.7794	1.9220	0.5747	7.8400
DNLO	6.7	228.0	27.9103	2.5142	0.6240	7.8356
DNEL	6.8	226.0	24.5027	2.1316	0.5223	7.9311
DNCK	8.6	142.0	0.8331	0.0854	0.1239	8.7622

Table A1. Cont.

Shrubland Type	Mean Annual Temperature (MAT)/°C	Mean Annual Precipitation (MAP)/mm	Soil Organic Carbon (SOC)/mg·g <sup>-1</sup>	Soil Total Nitrogen (TN)/mg·g <sup>-1</sup>	Soil Total Phosphorus (TP)/mg·g <sup>-1</sup>	pH of Soil
DNMM	8.6	168.0	14.7307	0.3528	0.1988	8.2056
DGAB	8.4	201.0	2.6518	0.2104	0.1480	9.0356
DGSX	8.3	202.0	1.7935	0.0655	0.1371	9.2689
DGNS	8.4	200.0	1.1354	0.0308	0.2121	9.1067
DGCM	8.1	127.0	1.1407	0.0287	0.1958	8.2256
DGEP	8.0	118.0	2.6956	0.1230	0.1424	9.0167
DGNP	8.1	119.0	1.7013	0.0803	0.2704	7.9667
DGNR	8.2	116.0	4.2169	0.2377	0.9946	8.2111
DGTC	8.3	146.0	1.6210	0.0720	0.2116	9.5744
DGHA	8.3	146.0	119.1405	11.4217	0.8279	5.9922
DSSC	7.2	436.0	0.3800	0.0186	0.1895	9.3847
AGRC	1.0	513.0	80.0124	7.7346	1.1016	5.4000
AGPF	1.3	520.0	80.9645	6.2458	0.6980	6.3489
AGRP	0.4	504.0	130.2043	14.3774	1.1939	5.5011
AGSG	0.0	495.0	18.7089	5.1608	1.3071	6.8867
AGBT	0.0	495.0	51.6689	11.4248	1.0994	6.9111
AGSA	0.0	495.0	62.2686	4.5667	0.7457	7.3756
AGSC	4.4	681.0	54.5681	5.9440	1.1925	6.0133
AGSS	4.4	681.0	106.3968	13.0798	1.4515	7.2644
AGHR	4.4	681.0	70.7029	8.2289	1.1664	5.8967
AGPP	2.6	605.0	79.1562	7.0774	0.9184	6.4967
AGBK	1.9	603.0	48.4780	4.7631	1.1045	7.2233
AGSQ	1.9	603.0	84.7738	8.3591	1.0411	7.2789
SSOD	10.9	600.0	1.5000	0.2100	0.5724	9.0615
SSVN	10.2	608.0	0.6312	0.1655	0.4106	8.7353
SSRH	12.9	550.0	1.1793	0.0655	0.5181	9.1766
SSSV	13.8	540.0	0.9938	0.0860	0.5856	9.0032
SSSO	10.6	564.0	0.8552	0.1596	0.5708	9.2357
SSZJ	10.7	616.0	0.7867	0.0941	0.6235	9.3220
SSRP	14.2	606.0	0.8466	0.1059	0.2407	7.1597
SSGB	14.2	606.0	0.8046	0.1704	0.6032	6.2511
SSLF	14.2	606.0	0.9986	0.2359	0.5227	5.7449
SSCG	13.7	658.0	1.8328	0.1724	0.7346	9.0609
SSCN	13.1	748.0	0.2472	0.0450	0.3287	9.5806
SSMA	16.0	719.0	2.1533	0.2551	0.5877	9.4934
SSFS	16.0	719.0	2.8770	0.2975	0.4767	9.1644
SSSS	14.8	763.0	2.3591	0.3061	0.7869	8.6214
SSLG	13.9	937.0	0.9197	0.3286	0.6079	6.2379
SSPP	13.9	937.0	0.8508	0.5763	0.7562	7.2977
SSCC	10.3	729.0	18.2905	1.5575	0.3802	8.3170
SSQB	14.3	832.0	19.1917	0.9301	0.1573	4.8156

Table A2. Pearson correlation between environmental factors and diversity indicators.

Factors	Richness	PD
Elevation	−0.125	−0.099
Slope	0.228	0.281
mean annual temperature (MAT)	0.268	0.254
mean annual precipitation (MAP)	0.475 **	0.530 **
organic carbon (TOC)	−0.032	0.01
total nitrogen (TN)	−0.035	0.006
total phosphorus (TP)	0.129	0.171
pH	0.022	−0.062

\*\* means significant correlation.

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