


## Article

# Scale Effects on the Relationship between Plant Diversity and Ecosystem Multifunctionality in Arid Desert Areas

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**Abstract:** Understanding the relationship between biodiversity and ecosystem multifunctionality is popular topic in ecological research. Although scale is an important factor driving changes in biodiversity and ecosystem multifunctionality, we still know little about the scale effects of the relationship between the different dimensions of biodiversity and ecosystem multifunctionality. Using plant communities in the northwest of the Qira Desert Ecosystem National Field Research Station of the Chinese Academy of Sciences in Qira County, Xinjiang, as the study object, we explored the scale effects of plant diversity and ecosystem multifunctionality at different sampling scales (5 m × 5 m, 20 m × 20 m, and 50 m × 50 m) and the relative contribution of different dimensions of diversity (species diversity, functional diversity, and phylogenetic diversity) to variation in ecosystem multifunctionality. At different scales, a significant scale effect was observed in the relationship between plant diversity and ecosystem multifunctionality. Species diversity dominated ecosystem multifunctionality at large scales (50 m × 50 m), and species diversity and ecosystem multifunctionality varied linearly between scales. Functional diversity made the greatest contribution in small scales (5 m × 5 m), and the relationship between phylogenetic diversity and ecosystem multifunctionality tended to show a single-peaked variation between scales, with a dominant effect on multifunctionality at the mesoscale (20 m × 20 m). The results of the study deepen the understanding of the scale effect of the relationship between plant diversity and ecosystem multifunctionality in arid desert areas, and help to further conserve plant diversity and maintain ecosystem multifunctionality.

**Keywords:** desert ecosystems; scale; plant diversity; ecosystem multifunctionality



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## 1. Introduction

Global climate change and habitat fragmentation play a significant negative role in biodiversity conservation and the sustainability of ecosystem functions. [1,2]. The study of the relationship between biodiversity and ecosystem function is important to enhance biodiversity and restore ecosystem function. Biodiversity includes species diversity, functional diversity, and phylogenetic diversity [3]. Early studies on the relationship between biodiversity and ecosystem function mostly considered the relationship between species diversity and single ecosystem function [4,5]. With the progress in research, scholars have found that functional diversity and phylogenetic diversity have significant effects on ecosystem function and cannot be replaced by species diversity, and considering only single ecosystem functions may underestimate the role of biodiversity in ecosystem function [6,7]. Therefore, the study of the relationship between multidimensional biodiversity and ecosystem multifunctionality contributes to a deeper understanding of the biodiversity maintenance mechanisms.

Studies on biodiversity in China and elsewhere tended to focus on different environmental gradients, disturbance levels and successional stages [8,9], with less attention paid to the scale dependence of biodiversity. However, biodiversity depends on the

number, composition and distribution of community species, and these factors are scale-dependent. [10,11]. The earliest studies on the relationship between plant diversity and ecosystem multifunctionality at different scales showed that alpha diversity was significantly positively correlated with ecosystem multifunctionality, with alpha diversity playing a dominant role [12]. Studies in subtropical regions further demonstrated that the positive correlation also showed a trend of rapid increase followed by a gentle increase [13,14], but the effect of  $\alpha$ -diversity on single ecosystem function is not significant in forest ecosystem studies [15]. Functional and phylogenetic diversity is also being studied in greater depth by researchers. A study by Dang et al. (2018) [16] in desert ecosystems has shown that functional diversity indices vary significantly between scales and shape different community structures. Changes in sampling scale have a significant effect on the divergence and aggregation of genealogical structure and the level of genealogical diversity [17]. Studies on cave plants have also shown significant differences in genealogical diversity between large and small scales [18]. Ecosystem multifunctionality and biodiversity interactions are also scale-dependent [19]. First, different species play different roles between scales, allowing inter-scale differences in ecosystem multifunctionality [20,21]. Second, as the scale increases, community differences lead to a constant exchange of materials and energy flows between communities, which affects ecosystem multifunctionality [22]. Finally, the composition and distribution of functional traits among species vary by scale. As scale changes, functional traits segregating or overlapping in trait space as scale changes, making ecosystem multifunctionality change in response [19].

Arid desert ecosystems are sensitive areas of global change and priority areas for biodiversity conservation. As an important part of terrestrial ecosystems, arid zones have distinctive climatic environments, geographical locations, and resource distribution patterns that make them unique in terms of biodiversity and ecosystem multifunctionality [23].

Located at the southern edge of the Taklamakan Desert, Xinjiang's Qira County has a dry climate with little rain and wind, and its ecosystem type is a typical temperate desert ecosystem. Due to its geographical location and topographical constraints, the region is ecologically fragile, and desertification is severe, which has led to a reduction in biodiversity and diminished ecosystem function services [24]. Considering the scale dependence of biodiversity and ecosystem multifunctionality, this study explored the relationship between multidimensional biodiversity and ecosystem multifunctionality based on three sampling scales (5 m  $\times$  5 m, 20 m  $\times$  20 m, and 50 m  $\times$  50 m), aiming to address the following scientific questions: (1) How do plant diversity and ecosystem multifunctionality relate to scale? (2) How do the relative contributions of species diversity, functional diversity, and phylogenetic diversity to ecosystem multifunctionality vary at different scales?

## 2. Materials and Methods

### 2.1. Overview of Experimental Area

The study area is located on the northern foot of the Kunlun Mountains and on the periphery of the oasis at the southern edge of the Tarim Basin (80°37'12" E, 37°2'0" N). The climate in the reserve is extremely arid, and water resources are scarce, with an average annual precipitation of 35.1 mm and a potential annual evaporation of 2595.3 mm [25]. The main types of soil are gray-brown desert soil, gray desert soil, and wind-sand soil, with a high degree of soil salinity [26]. The natural vegetation is dominated by perennial desert plants, with the main species including *Populus euphratica*, *Tamarix chinensis*, *Alhagi sparsifolia*, *Salsola collina*, and *Hexinia polydichotoma*.

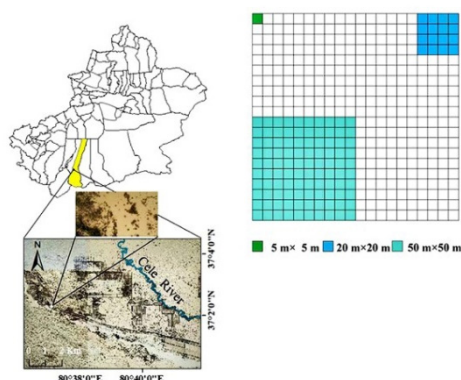
### 2.2. Research Method

#### 2.2.1. Sample Setting

A 100 m  $\times$  100 m sample plot was set up in the northwest of the Qira Desert Ecosystem National Field Research Station of the Chinese Academy of Sciences in July 2019, where quadrats of three scales (50 m  $\times$  50 m, 20 m  $\times$  20 m, and 5 m  $\times$  5 m) were set up. Using the 5 m  $\times$  5 m quadrat as the basic unit, 100 quadrats were randomly selected at each scale

within the sample plots. Where each  $20\text{ m} \times 20\text{ m}$  quadrat contains 16 quadrats of  $5\text{ m} \times 5\text{ m}$  and each  $50\text{ m} \times 50\text{ m}$  quadrat contains 100 quadrats of  $5\text{ m} \times 5\text{ m}$  (Figure 1).

Qira.



**Figure 1.** Location of the study area and the investigated plots.

### 2.2.2. Collection of Plant Samples

Plant species information, abundance, and plant height were recorded in the field at a minimum sampling scale of  $5\text{ m} \times 5\text{ m}$ . Three  $1\text{ m}^2$  samples were selected on the diagonal of each  $5\text{ m} \times 5\text{ m}$  square to record and calculate the herbaceous abundance within the  $5\text{ m} \times 5\text{ m}$  square. In a  $5\text{ m} \times 5\text{ m}$  sample, approximately 30 mature leaves were collected from each plant species, and three were selected to measure leaf length (LL), leaf width (LW), leaf thickness (LT), and fresh leaf weight. All leaves were taken back to the laboratory to be dried, ground, and used for the measurement of leaf dry matter content (LDMC), leaf carbon content (LC), leaf nitrogen content (LN), and leaf phosphorus content (LP) indexes.

### 2.2.3. Collection of Soil Samples

The soil was sampled in  $5\text{ m} \times 5\text{ m}$  units, with the diagonal method of taking a 0–20 cm surface layer of soil at the center, using an aluminum box to store the soil and calculate the soil water content, and then taking a sample in a sealing bag for the determination of other soil physical and chemical properties. The method of determination [27] is shown in Table 1.

**Table 1.** Soil index and determination method.

Soil Factor	Method
Soil water content	Drying and weighing method
pH	Acidimeter
Electrical conductivity	Residue method
Organic carbon	Potassium dichromate dilution heating method
Total phosphorus	Molybdenum antimony colorimetric method
Available phosphorus	Spectrophotometry
Total nitrogen	Kjeldahl method
Nitrate nitrogen	UV spectrophotometry
Ammonium nitrogen	UV spectrophotometry

## 2.3. Data Calculation and Analysis

### 2.3.1. Calculation of Plant Diversity

In this study, we selected species diversity indices, namely Shannon–Wiener diversity index, Simpson diversity index, Margalef richness index, and Pielou evenness index ([28]; functional diversity indices, including FRic richness index, FEve evenness index, FDiv divergence index, and RaoQ quadratic entropy index [29,30]; and phylogenetic diversity indices, including the mean interspecific distance index (MPD), mean nearest in-

terspecific distance (MNTD), and Faith diversity index (PD) (for calculation methods, see Supplementary Table S1) [31,32].

### 2.3.2. Calculation of Ecosystem Multifunctionality

In this study, soil environmental factors (total nitrogen, total phosphorus, ammonium nitrogen, nitrate nitrogen, fast-acting phosphorus, and organic matter) were used as indicators of ecosystem multifunctionality, and the “Z-score” mean method was used to calculate ecosystem multifunctionality, represented by the formula [33,34]:

$$MF_a = \sum_i^F \frac{g(r_i(f_i))}{F}.$$

In the above equation,  $MF_a$  represents ecosystem multifunctionality,  $f_i$  represents the measured value of function  $i$ ,  $r_i$  is the mathematical function that converts  $f_i$  into a positive value,  $g$  represents the normalization of all measured values, and  $F$  represents the number of functions measured.

### 2.3.3. Data Analysis

Excel 2019 was used for the initial processing and calculation of the data. Differences in plant diversity and ecosystem multifunctionality between the three scales (5 m × 5 m, 20 m × 20 m, 50 m × 50 m) were analyzed in SPSS 26.0 using one-way analysis of variance (ANOVA). When the variance was equal, the least significant difference (LSD) method was used for the results of multiple comparisons; when the variance was not uniform, the results of multiple comparisons were tested using a non-parametric test. The Kolmogorov–Smirnov test (K–S test) were used to test the normality of ecosystem multifunctionality. Random sampling of the sample plot is done in R4.1.3. A community phylogenetic tree was created in R4.1.3 using the “VPhyloMaker” package [35]. The species diversity index, functional diversity index, and phylogenetic diversity index were calculated using the “vegan”, “FD”, and “picante” packages, respectively.

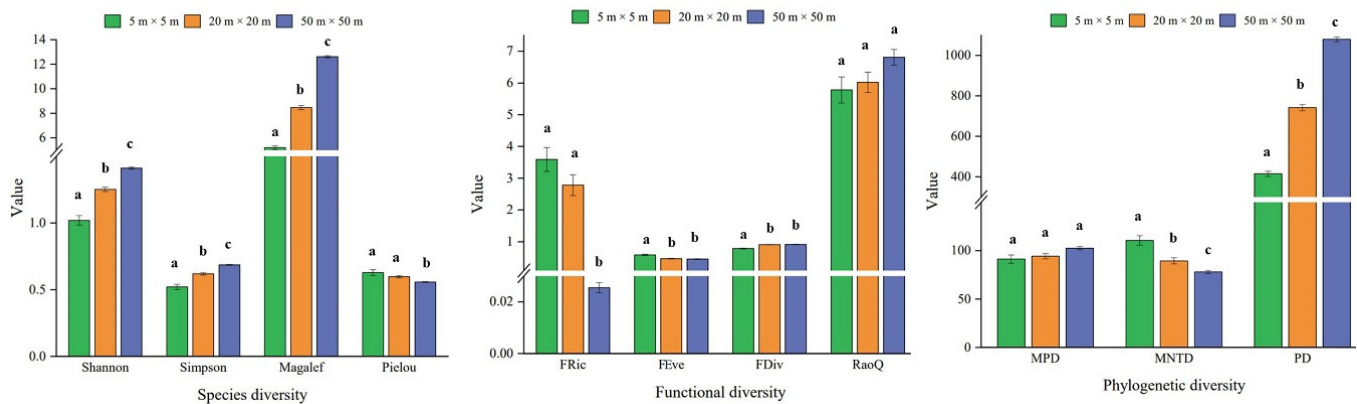
The model was selected in R4.1.3 using the function “dredge” from the “MuMin” package [36], based on the corrected Akaike’s information criterion (AICc;  $\Delta AICc < 2$ ) [37]. A selection procedure was used to select the best predictor of ecosystem multifunctionality, and when multiple models were selected, model averaging was performed based on AICc weights. The model residuals were inspected for constant variance and normality. All predictors and response variables were standardized before the model was constructed. Predictors were log-transformed as necessary before analysis to meet the assumptions. The model calculated relative explanatory rates for each diversity index and compared them with the total explanatory rates for all diversity indicators in the model, after which the explanatory rates for the indices in the model were categorized and summed by species diversity, functional diversity, and phylogenetic diversity to obtain the relative importance of different diversity dimensions (species diversity, functional diversity, and phylogenetic diversity) as drivers of ecosystem multifunctionality.

## 3. Results

### 3.1. Characteristics of Plant Diversity

Among the species diversity indices, the Shannon diversity index, Simpson diversity index, and Margalef richness index tended to increase with scale and showed significant differences between scales ( $p < 0.05$ ), and the Pielou evenness at large scales (50 m × 50 m) was significantly smaller than at small (5 m × 5 m) and medium scales (20 m × 20 m). For the functional diversity index, the RaoQ index showed an increasing trend from small to large scales. The FRic richness index, FEve evenness index, and FDiv divergence index were significantly different between small and large scales. The MNTD index of phylogenetic diversity showed a decreasing trend with increasing scale. The PD index showed an

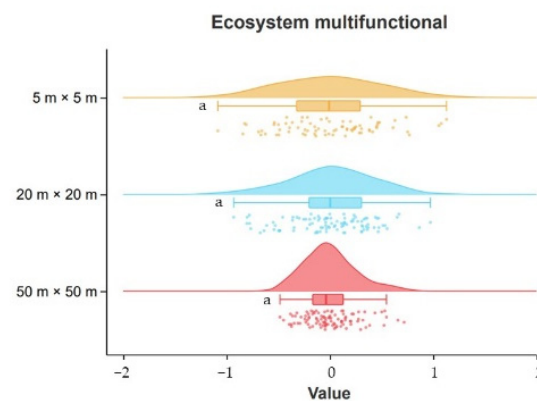
opposite trend and was significantly different between scales, while the MPD index was not significantly different between scales ( $p > 0.05$ ) (Figure 2).



**Figure 2.** Characteristics and differences in plant diversity between scales (Mean  $\pm$  SE). Note: error lines are standard errors; different lowercase letters on the error line for the same diversity index indicate highly significant differences between data ( $p < 0.05$ ).

### 3.2. Characteristics of Ecosystem Multifunctionality

Using the K–S test and Raincloud plot (Figure 3), the ecosystem multifunctionality index calculated by the mean method was distributed normally at all three scales, with the values of the multifunctionality index varying from  $-1.085$  to  $1.129$  for small-scale samples,  $-0.931$  to  $0.973$  for medium-scale samples, and  $-0.484$  to  $0.718$  for large-scale samples, but the ecosystem multifunctionality index did not vary significantly between scales ( $p > 0.05$ ).



**Figure 3.** Characteristics and differences in ecosystem multifunctionality between scales. Note: Error lines are standard errors; same lowercase letters on the error line indicate no significant differences between data ( $p > 0.05$ ).

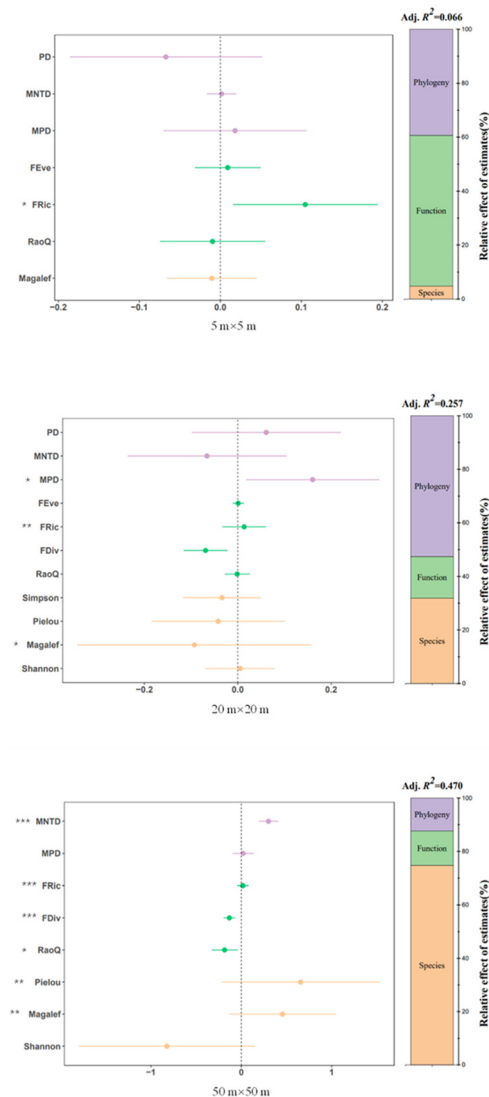
### 3.3. Characterization of the Relationship between Diversity and Multifunctionality

The results of the variance decomposition showed that there was a scale effect on the contribution of different dimensions of diversity to ecosystem multifunctionality. The FRic, FEve, and RaoQ indexes of plant functional diversity explained 56% of the variation in multifunctionality together on small scales, and they were the main factors driving ecosystem multifunctionality. The FRic index was significantly correlated with ecosystem multifunctionality.

However, at the mesoscale, phylogenetic diversity was the main factor shaping multifunctionality, with the MPD, MNTD, and PD indices accounting for 53% of multifunctionality. The MPD index was significantly correlated with multifunctionality, while the functional diversity of plants explained less of multifunctionality, but the FRic index

was still significantly correlated with multifunctionality. Species diversity had a stronger influence on multifunctionality, with the Margalef index being significantly correlated with multifunctionality.

The contribution of species diversity to multifunctionality reached a maximum of 75% on large scales, and it was the main explanatory factor for ecosystem multifunctionality. The Margalef and Pielou indexes were significantly correlated with multifunctionality. Among the functional diversity indices, the FRic, FDiv, and RaoQ indexes together contributed to 13% of the variation in multifunctionality and were all significantly correlated with multifunctionality. Among the phylogenetic diversity indices, the MNTD index was significantly correlated with multifunctionality (Figure 4).



**Figure 4.** Relationship between plant diversity and ecosystem multifunction at different scales. Note: \*, \*\* and \*\*\* represent  $p < 0.05$ ,  $p < 0.01$  and  $p < 0.001$ .

## 4. Discussion

### 4.1. Plant Diversity at Different Scales

Plants are driven by interspecific interaction and environmental influence, resulting in certain spatial distribution patterns [38]. When spatial scales change, plant community structure and diversity characteristics also change. Exploring the relationship between sampling scale and plant diversity can contribute to a more comprehensive understanding of community diversity trends and species coexistence mechanisms [39]. Our study found that species diversity was strongly scale-dependent [40]. The Margalef richness index



showed an increasing trend with increasing scale. This is because the study site is highly windy and sandy, and water resources are scarce; thus, plants are clumped and aggregated to avoid wind and sand attacks and water scarcity [40], which limits the number of plant species that can be accommodated at small scales. As the sampling scale increases, the number of plant species increases, the composition of dominant species at each level becomes more diverse, and the Margalef index also increases. The Shannon diversity index and Simpson diversity index also increased with expansion in scale because, as the scale increases, habitat heterogeneity, the number of plants that can be accommodated, the number of species, and the level of species increases, and the structure of plant communities becomes more integrated and complex [41]. In addition, the Shannon diversity, Simpson diversity, and Margalef richness indexes showed a rapid increase and then a steady climb with the expansion of the scale, which is similar to the results of Deng et al. (2015) [14] in mixed coniferous forests of *Pinus radiata*. This indicates that the diversity of desert plant species increases with scale and plateaus after reaching a certain threshold [42].

Functional diversity is an extremely important part of plant diversity and plays an irreplaceable role in shaping the structure of plant communities and altering ecosystem functions [43]. Previous studies have shown that functional diversity varies with scale due to phenotypic plasticity [44–46]. Similar results were obtained in our study. The FEve evenness index and the FRic richness index both showed a decreasing trend with increasing scale and were opposite the trend in species richness, with significant differences between scales ( $p < 0.05$ ); this indicates that species diversity and functional diversity have relatively independent trends [47]. This may be attributed to the obvious environmental filtering effect of the arid zone, where the functional composition of species is restricted to a certain range of functional traits, resulting in a more homogeneous pool of functional traits in this study area and an increase in species richness, leading to a more refined division of ecological niches rather than greater functional diversity [48], thus producing a different trend in functional diversity from that of species diversity [49,50].

The FDiv divergence index shows the degree of overlap in ecological niches between species within a community; that is, the heterogeneity of community character values [51], and a higher FDiv index indicates a high degree of ecological niche differentiation and higher resource use [52,53]. In our study, the FDiv index was significantly greater at large scales than at small scales, probably because, as scale increases, plant competition for the same or several habitat-specific resources diminishes, and ecological niches diverge further; thus, the FDiv index increases. The results of this study showed that the FRic richness index tended to decrease with increasing scale and was negatively correlated with the Shannon diversity index. This may be because functional richness is influenced not only by the functional ecological niche of the species but also by the range of functional trait values [54]. To overcome extreme drought conditions, functional traits of species in the study area are prioritized in response to selection pressure to adapt to drought [48,55], and functional traits tend to develop homogeneously, with increasing scale leading to a continuous increase in species richness followed by a deepening of functional redundancy [56,57], the FRic richness index declines, and the results of previous studies in *Pinus* oak forests in the Qinling Mountains are consistent with our study [58]. The negative correlation between species diversity and functional diversity because of scale expansion suggests that species diversity alone should not be considered when extrapolating functional diversity but also species differences and functional redundancy between scales [58].

In our study, the PD and MNTD indices varied significantly with scale, with the PD index increasing and the MNTD index decreasing with scale. This is probably because there is a significant correlation between the PD index and the Margalef index [59], with species richness increasing with scale, which is conducive to the maintenance of genealogical diversity at large scales. Genealogical structure is one of the most important expressions of community structure, as it reflects the process of community construction and evolution. Numerous studies have shown that the divergence or aggregation of genealogical structure is related to scale size [60–62]. The MNTD index in our study decreases with increasing

scale and is significantly different between the three scales, suggesting that the community genealogical structure gradually moves from divergence to aggregation with increasing scale [63]. Therefore, the community is composed of more distantly related species on small scales and more closely related species on large scales. This is probably because of the low variation in habitat conditions on a small scale, combined with the harsh environmental conditions in the study area, where competition for a particular resource between species makes competitive exclusion the dominant community-building process. Therefore, the genealogical structure tends to diverge. At large scales, habitat heterogeneity increases, habitat-filtering ecological processes begin to dominate [64], and the genealogical structure gradually tends to agglomerate. Studies in the evergreen broadleaf forests of the Gutian Mountains and in the tropical rainforests of Panama [61,65] have also shown that competitive exclusion at small scales has a negative effect on the coexistence of closely related species, and that there is a tendency for the genealogical structure of communities to change from divergence to aggregation with increasing scale, but when the spatial scale exceeds a certain area, there is no correlation between genealogical structure and scale, and the genealogical structure becomes aggregated [66].

#### *4.2. Ecosystem Multifunctionality at Different Scales*

Early studies of ecosystem multifunctionality focused on the effects of species diversity on a single ecosystem function on the same scale [50,67–70]. As research has progressed, researchers have realized that differences in the choice of scale of study influence the expression of ecosystem multifunctionality [20]. However, the results of this study showed that ecosystem multifunctionality did not diverge significantly among the three scales. This is probably because variations in ecosystem multifunctionality in this study area are more related to changes in species composition, environmental conditions, or temporal scales than to spatial scales [33,71,72]. Our study area is located in an arid desert region where plant species composition is highly dependent on soil water and salinity conditions, which has led to a high degree of similarity in the overall community species composition of the region; however, significant differences in ecosystem multifunctionality between scales depend not only on significant differences in species diversity between scales but also on diverse community structure [73]. In addition, this study did not consider climatic conditions and time scales when discussing ecosystem multifunctionality, but numerous studies have shown that ecosystem multifunctionality varies significantly depending on the climatic conditions or time span of the study [12,74]. Finally, although three scales—large, medium, and small—were chosen for this study, the largest scale was only 50 m × 50 m. There is still much potential to expand the area of the sampling scale; thus, work on larger scales should be carried out in the future.

#### *4.3. Relationship between Plant Diversity and Ecosystem Multifunctionality at Different Scales*

The relationship between plant diversity and ecosystem multifunctionality varies with scale. Our study found that the highest levels of species diversity at large scales explained the greatest amount of variation in ecosystem multifunctionality, suggesting that the maintenance of multiple ecosystem functions simultaneously in this study area required a greater number of species and higher levels of species diversity to support them and that high species diversity could effectively support the maintenance of ecosystem multifunctionality. This is probably due to ecological niche differences on large scales when different species or functional groups coexist in resource-limited communities [75], where larger scales have more species and therefore have complementary advantages in resource use and, thus, the greatest explanatory power for ecosystem multifunctionality. The relationship between species diversity indices and multifunctionality also varied between scales, with the Margalef index being significantly correlated with ecosystem multifunctionality at the meso- and macro-scales but not at the small-scale, and the Pielou index was significantly correlated with ecosystem multifunctionality at the macro-scale. This demonstrated that under the dimension of species diversity, species richness and species evenness played a



dominant role in driving multifunctionality. This likely results from the fact that the maintenance of ecosystem multifunctionality requires a high level of species diversity [72,76], and a smaller quantity of species cannot support all ecosystem functions [77]. Domestic and international studies have shown that larger vegetation communities and a larger number of species increase the use of habitat resources by plants and play an important role in maintaining high levels of ecosystem multifunctionality [69,78–81]. Species are relatively sparse in desert areas, and when the scale is small, the number of species in the sample is relatively infrequent, the Margalef index is comparatively low, the level of species diversity is not high, and the impact on ecosystem multifunctionality is limited. When the scale increases, the spatial ecosystem heterogeneity of the sample increases, it can accommodate a larger number and more species of plant samples, the Margalef index and Pielou indexes increase, and the explanatory power of species diversity on multifunctionality is strengthened, which is consistent with the hypothesis that species diversity is positively correlated with ecosystem multifunctionality [82].

Studies have shown that species diversity is no substitute for functional diversity to simply quantify multifunctionality [70], and in recent years, many studies have demonstrated that functional diversity has a stronger explanatory role for multifunctionality [83–85]. In our study, functional diversity contributes most to multifunctionality at a small scale, which is determined by a combination of species composition and structure. At small scales, species richness is low to allow for an increase in ecological niche space, which facilitates the expansion of the range of functional plant traits [86], so functional richness is at a higher level at small scales, which indicates a higher proportion of available resources [79], thus allowing functional diversity to dominate variations in ecosystem multifunctionality at small scales. In addition, the FRic index of functional diversity was significantly correlated with ecosystem multifunctionality at all three scales ( $p < 0.05$ ), and the FDiv index was highly significantly correlated with ecosystem multifunctionality at large scales. The FRic index is a dominant driver of ecosystem multifunctionality at different scales, probably because plant species are limited in desert areas, and changes in species community composition and structure directly alter functional richness [87], which in turn affects single ecosystem functions and thus ecosystem multifunctionality. In addition, functional dispersion is significantly correlated with ecosystem multifunctionality at large scales, probably because as habitat heterogeneity increases on larger scales, variation in functional traits increases, competition among species decreases, complementarity of functional traits for resource use increases, overlap of species' ecological niches decreases, and the overall degree of resource use within scales increases, which also has a positive effect on the maintenance of ecosystem multifunctionality [86]. The results are also similar to the findings of Huang et al. (2019) [79] in Yunnan.

Genealogical diversity reflects the historical course of species evolution [88], can express community information not represented by species diversity and functional diversity, and is an important component in the study of the relationship between plant diversity and ecosystem multifunctionality [89–91]. In our study, genealogical diversity played a dominant role in ecosystem multifunctionality at the mesoscale, probably because habitat heterogeneity has an important influence on the maintenance of genealogical diversity. The results of the study on typical areas of karst landscapes showed that phylogenetic diversity had a single-peaked change with increasing habitat heterogeneity and was greatest in areas of moderate habitat heterogeneity [59]. In addition, a study by Li et al. (2021) [92] in the Daiyun Mountains also showed that phylogenetic diversity showed an intermediate peak with altitude, which was similar to the results of our study. At the mesoscale, habitat heterogeneity is at a moderate level compared to the large and small scales, which contributes more to genealogical diversity, and higher levels of genealogical diversity increase the rate of explanation for ecosystem multifunctionality. Our study also showed that the MPD index was significantly correlated with ecosystem multifunctionality on the large scale, and the PD index was not significantly correlated with ecosystem multifunctionality on any scale, indicating that the proximity of affinities among species plays a major role

in maintaining ecosystem multifunctionality at different scales. Although the PD index increases with the number of species, the total number of plant species in the desert area is limited, and when the PD index reaches a certain value, it will not continue to promote the maintenance of ecosystem multifunctionality. In our study area, species relatedness tended to change from distant to close, based on scale expansion. This is likely because the habitat filtering effect in the study area increases with scale, the extreme arid habitat conditions make it easier for species with similar life history strategies to survive [93,94], and similar survival strategies and close affinities use resources in similar ways, allowing limited resources to be fully utilized [95]. Genealogical structure has a strong influence on ecosystem multifunctionality, so the correlation between MNTD and MPD indexes and ecosystem multifunctionality is also stronger than that between PD indices.

## 5. Conclusions

We uncovered a significant scale effect in the relationship between plant diversity and ecosystem multifunctionality. Differences in sampling scales altered the composition and distribution of species in plant communities. The relative contribution of plant diversity to ecosystem multifunctionality also changed consequently. This highlights the close coupling between scale effects and ecosystem multifunctionality in the plant communities of this study area. Therefore, we will continue to expand the sampling scale in the next research work, aiming to better enhance plant diversity and maintain ecosystem function.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/f13091505/s1>, Table S1: Calculation formula of plant diversity indexes.

**Author Contributions:** Conceptualization, J.L. and G.L.; methodology, J.L.; software, J.L., H.W. and D.H.; writing—original draft preparation, J.L.; writing—review and editing, J.L., L.J. and D.H.; supervision, G.L. funding acquisition, G.L. All authors have read and agreed to the published version of the manuscript.

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