sustainability

Article

Distribution Pattern of Species Richness of Endemic Genera in Mountainous Areas of Southwest China and Its Influencing Factors

Aoxiang Chang [1], Ting Wu [1], Bowen Li [1], Dezhi Jiao [1], Yushu Wang [1], Dan He [1], Zihan Jiang [2] and Zhenyu Fan [1,*]

1 School of Life Science and Agriculture Forestry, Qiqihar University, Qiqihar 161006, China; changaoxiang928@sina.com (A.C.); wuting990227@sina.com (T.W.); w13684569943@sina.com (B.L.); jdz_13909@163.com (D.J.); wangys1019@126.com (Y.W.); hepan1990@163.com (D.H.)
2 CAS Key Laboratory for Plant Diversity and Biogeography of East Asia, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650201, China; jiangzihan@mail.kib.ac.cn
* Correspondence: fzy@qqhru.edu.cn; Tel.: +86-1563624337

Abstract: China's southwest mountainous region is one of the hotspots of biodiversity in the world. However, the study on the pattern of species richness distribution of endemic plants in this region and its influencing factors is still in the exploration stage. A clear regional spatial distribution pattern of plants and its influencing factors are very important for the protection and management of plant diversity in southwest China. In this study, 511 county-level regions in the southwest mountainous region were taken as examples to establish a plant species resource bank in the southwest mountainous region, and the distribution pattern of the proportion and abundance of endemic plant families and genera was analyzed based on 19 climate and environmental factors and 8 human disturbance factors in the southwest mountainous region. The geographical weighted regression model (GWR) was used to reveal the main factors affecting the spatial distribution of species. The results showed that: (1) A total of 4688 species investigated in the southwest mountain belong to 19 families and 32 genera. (2) The endemic species richness in the southwest mountainous region showed a significant uneven spatial pattern, mainly concentrated in the Heng Duan Mountain area, southwest Sichuan and northern Yunnan area, and the Ruoergai-Hongyuan area of West Sichuan Plateau. (3) The results of the GWR model showed that the diurnal mean temperature range, precipitation seasonality and distance from the main road had significant effects on species richness. The study on the distribution of endemic genera and their influencing factors in the southwest mountainous region has important implications for the exploration of the evolutionary history and species conservation of the mountain flora.

Keywords: southwest mountain; richness; spatial pattern; driving force

check for updates

Citation: Chang, A.; Wu, T.; Li, B.; Jiao, D.; Wang, Y.; He, D.; Jiang, Z.; Fan, Z. Distribution Pattern of Species Richness of Endemic Genera in Mountainous Areas of Southwest China and Its Influencing Factors. *Sustainability* **2024**, *16*, 3750. https://doi.org/10.3390/su16093750

Academic Editors: Francisco Guerrero, Juan Diego Gilbert and Andreas Reul

Received: 29 March 2024
Revised: 27 April 2024
Accepted: 27 April 2024
Published: 30 April 2024

1. Introduction

The spatial distribution pattern of biodiversity has a very important impact on ecosystem services and functions and is one of the hot and foremost issues in ecological research [1,2]. A large number of studies have been conducted on various mountain ranges and different types of species across the globe, and the mechanisms of their impact have been explored [3]. Studies have shown that species richness is driven by evolutionary history, ecological processes, human disturbance, modern environment and other factors [4], among which modern environmental conditions and human disturbance factors are considered to be the main driving factors of species richness distribution pattern [5–7]. In terms of southwest China, determining the main driving forces of regional species distribution spatial patterns requires further study. Modern environmental conditions mainly include modern climate (heat, moisture and seasonal changes, etc.) and habitat heterogeneity, which lead to the energy hypothesis and environmental stability hypothesis. The energy hypothesis holds that the species richness of a region is mainly controlled by energy, and the higher the energy, the higher the species richness [8,9]. The environmental stability hypothesis holds that stable environmental conditions are conducive to the specialization and adaptation of species, and narrow the ecological niche, which is conducive to accommodating more species [10]. These hypotheses explore the main factors in the formation of species richness based on different influencing factors. At present, these hypotheses have been tested in some studies. Human disturbance refers to the process of human beings' purposeful transformation or ecological construction of the natural environment, such as land burning and planting, deforestation, night lighting, farmland fertilization, road construction, road and land use structure change, etc. [11,12]. Many plant groups and species are closely related to human disturbance, and various disturbance modes will change the biological relationship, resource pattern and ecological process of the ecosystem, as well as the role and status of the original dominant population of the plant community in the wider community and the competition between various species, posing a great threat to biodiversity [13,14]. These studies have laid a good foundation for an in-depth understanding of the diversity and spatial distribution of mountain flora and fauna. However, similar studies mainly focus on the widespread species in mountainous areas, leaving a gap in the exploration of the distribution pattern and formation mechanism of species richness of endemic plants in mountainous areas.

Specificity has always been a hot topic in bio-geography research [15]. In a particular region, its geographical distribution pattern and richness are not only directly related to the current terrain, climate, land use and other factors [16,17], but also closely related to the geological evolution and climate change in the historical period [18,19]. Studying the differentiation pattern of endemic species in a certain region is the key to studying the nature, origin, formation and evolution of flora. At the same time, species specificity is a hot issue in the field of biodiversity conservation, and the focus of species conservation. In addition, in biodiversity conservation research, endemism has become a very important topic because it is key to predicting biodiversity hotspots and identifying priority protected areas [20].

The southwest mountainous region is one of the hotspots of species diversity in China [21], due to its concentrated environmental gradient and highly heterogeneous habitats, and relatively low intensity of human disturbance, and the fact that it has often served as a refuge for a large number of species and as a cradle for the differentiation and propagation of emergent floras in periods of geological history.

Therefore, the southwestern mountains have rich species resources [22]. The southwest mountainous region is the main habitat for a variety of plants and animals, and more than half of them are endemic species [23]. Therefore, the southwest mountainous region is the key content and ideal region for the study of species richness distribution patterns, but there is still a lack of research on endemic species diversity patterns in this region. An in-depth study on the distribution pattern of endemic plants in the southwest mountainous region and the relationship between them and environmental factors and an exploration of the main factors affecting the endemic species richness in the southwest mountainous region is necessary. It is helpful for the protection, introduction, development and utilization of endemic plant resources in southwest mountainous areas of China, and also has certain significance for the study of classification, phylogeny and genetic diversity protection of endemic plants in southwest mountainous areas of China.

This study explored the distribution pattern of the richness of endemic genera in southwest China, combined with environmental factors and anthropogenic interference factors, and explored the main driving force of the spatial distribution pattern of endemic genera in southwest China, as well as more suitable growing environments for endemic plants in this region. We hope to provide references for the conservation and research of endemic plants in the southwestern mountains.

2. Materials and Methods

2.1. Study Area

This study area is the southwest mountainous region, located at 20°54′–34°55′ N, 78°24′–111°2′ E, including Yunnan, Guizhou, Sichuan, Chongqing and Xizang with an area of about 2,340,600 square kilometers, accounting for 24.5% of China's land area [24] (Figure 1). The terrain of the study area is relatively complex, but it can be clearly divided into three categories: the high mountain area of the Yunnan-Guizhou Plateau, the high mountain area of the Qinghai-Tibet Plateau, and the Sichuan Basin and its surrounding mountains [25]. Various terrain types are evenly distributed in the study area, including lowland basin, plain and lowland hills, which account for 14.34%, 12.22% and 15.89% of the total area, mainly concentrated in Sichuan Basin, Guangxi region, Guizhou Plateau, southwest Yunnan, and other low altitude areas. The Heng Duan Mountain is the main area of the gorge, and under the influence of the Jinsha River, the Nujiang River and the Lancang River, it presents a great surface cut and has a great slope [26]. The climate is mainly subtropical monsoon climate and plateau mountain climate, with uneven average annual temperature distribution and abundant rainfall [27].

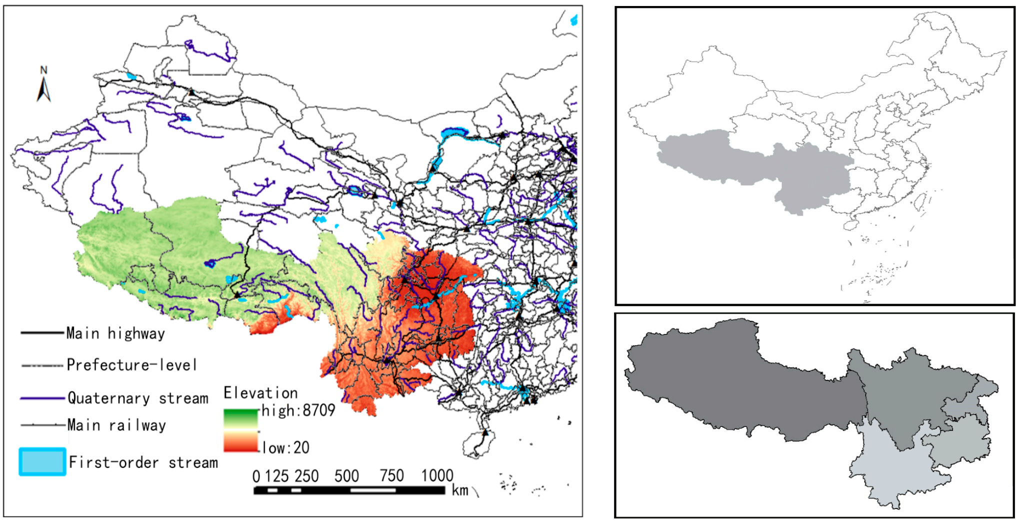


Figure 1. Map of the studied area of the southwest mountainous region (20°54′–34°55′ N, 78°24′–111°2′ E): Yunnan, Guizhou, Sichuan, Chongqing and Xizang provinces.

2.2. Species Distribution Data

First, the endemic genera of plants in the southwest mountainous region were preliminarily identified through a literature review and expert consultation [28,29]. Distribution data of endemic genera in the southwestern mountains were obtained from the Flora of China database (http://www.iplant.cn/frps (accessed on 25 March 2023)). Artificial cultivated species were excluded, and subspecies grades such as varieties and variants were counted as an independent taxon, and distribution information was unified to county-level units [30]. The final dataset included 4688 species, 32 genera, 19 families, 511 county-level data, and 21,735 distribution information datapoints of endemic plants in southwest mountainous areas.

2.3. Environment, Human Interference Data

Apart from the influencing factors used in Xu et al. [31] on the relationship between *Quercus* plant richness and climate in the northern hemisphere and in the study of Zhang Feng ying et al. [24] on the relationship between Fagaceae species richness and environment in southwest China, this study also included human activity factors, altitude, latitude and longitude as explanatory variables, selecting 19 common climate factors (including energy and moisture factors) used in plant species richness research [32,33].

The original resolution is 1 km × 1 km. The average value of climate factors in each county was extracted as the environmental data of the county. Eight kinds of human interference factors were selected, and the average value of each influencing factor in each county was taken as its human interference data (Table 1). The extraction and calculation of environmental data and human interference data are completed by the ArcGIS version 10.8 (ESRI. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute, 2011).

Table 1. Climate and environmental factors and human disturbance factors in the southwest mountainous area.

Impact Factors	Data Sources
Annual mean temperature (AMT) Mean diurnal range (MDR) Isothermality (IS) Temperature seasonality (TS) Max temperature of warmest month (MTWM) Min temperature of coldest month (MTCM) Temperature annual range (TAR) Annual precipitation (AP) Mean temperature of wettest quarter (MTWQ) Mean temperature of driest quarter (MTDQ) Mean temperature of warmest quarter (MTW) Mean temperature of coldest quarter (MTCQ) Precipitation of wettest month (PWM) Precipitation seasonality (PS) Precipitation of wettest quarter (PWQ) Precipitation of driest quarter (PDQ) Precipitation of warmest quarter (PW) Precipitation of Driest Month (PDM) Precipitation of coldest quarter (PCQ)	WorldClim Batabase (https://worldclim.org/version2.1 (accessed on 11 April 2023)) (1970–2000)
Night Lights (NL) Population GDP	Resource and Environmental Science and Data Center (https://www.resdc.cn/ (accessed on 11 April 2023)) (2020)
The distance to the railway (DR) The distance to the expressway (DE) Distance to main road (DMR) Distance to secondary main road (DSMR) Distance to the city center (DCC)	Open Street Map (https://www.openstreetmap.org/ (accessed on 11 April 2023)) (2020)
Elevation	(https://topographic-map.com/ (accessed on 11 April 2023))
Latitude Longitude	(https://www.xcditu.com/ (accessed on 11 April 2023))

2.4. Construction of Geographical Weighted Regression (GWR) Model

Since traditional regression models, such as linear regression, linear fitting and least square method assume that the regression results are not affected by the region, they cannot solve the spatial correlation well. However, the GWR model carries out regression analysis in every place and adds the sub-data of each region into the regression model, so as to obtain the regression coefficient of each region [34].

2.5. Species Richness Statistics

Species richness is expressed as the number of species: First of all, the projection transformation of the equal area conic projection (Asia North Albers Equal Area Conic) was performed using ArcGIS 10.8; then, the cropped county vector data in the southwest mountainous region was correlated with the species richness of each county, and the total species number in the county was taken as the species richness of the grid. Finally, using Jenks grading function in ArcGIS, species richness was divided into five levels [35].

2.6. Correlation Analysis between Species Richness, Environmental Factors and Human Disturbance Factors

First, the logarithmic transformation of Y = log(Y + 1) is performed on the data that does not satisfy the normal distribution. Secondly, a geographical weighted regression (GWR) model was constructed to investigate the relationship between species richness and various environmental factors and human disturbance factors. In order to further explore the influence degree of energy, water and human disturbance, GWR models were constructed to analyze species richness and the above environmental factors, respectively, and then the influence degree of energy, water and human disturbance models was evaluated through R^2. At the same time, in order to eliminate the influence of multicollinearity among various environmental factors, the Ordinary Least Square Regression model was first used before the geographical weighted regression analysis. We chose the variance inflation factor model of less than 7.5 to be analyzed.

3. Results

3.1. Family Species Statistics

There are 4688 species of endemic plants in the southwest mountainous region, belonging to 19 families in terms of family composition, including more than 200 species of *Rhododendraceae*, *Compositae*, *Ranunculaceae*, *Ledanaceae*, *primrose family*, *papaveraceae* and 13 other families (Figure 2), giving us a total of 4239 species, accounting for 90.40% of the total number of endemic plants investigated. The southwest mountain plants belong to 32 genera, and the southwest mountain plants are the main distribution and differentiation centers of some characteristic genera, such as 663 species of *Rhododendron*, which accounts for 14.13% of the endemic plants surveyed. There are 382 species of *Corydalis*, accounting for 8.14% of the endemic plants. There are 362 species of *Primula*, accounting for 7.72% of the endemic plants surveyed. Figure 3 shows the proportion of 19 genera with more than 100 endemic species, including a total of 4435 species, accounting for 94.58% of endemic plants in the southwest mountain. Among them, there are 11 genera including *Pedicularis*, *Rhododendron*, *Corydalis*, *Primula*, *Saxifraga*, *Saussurea* and *Gentiana*. There are more than 200 species overall.

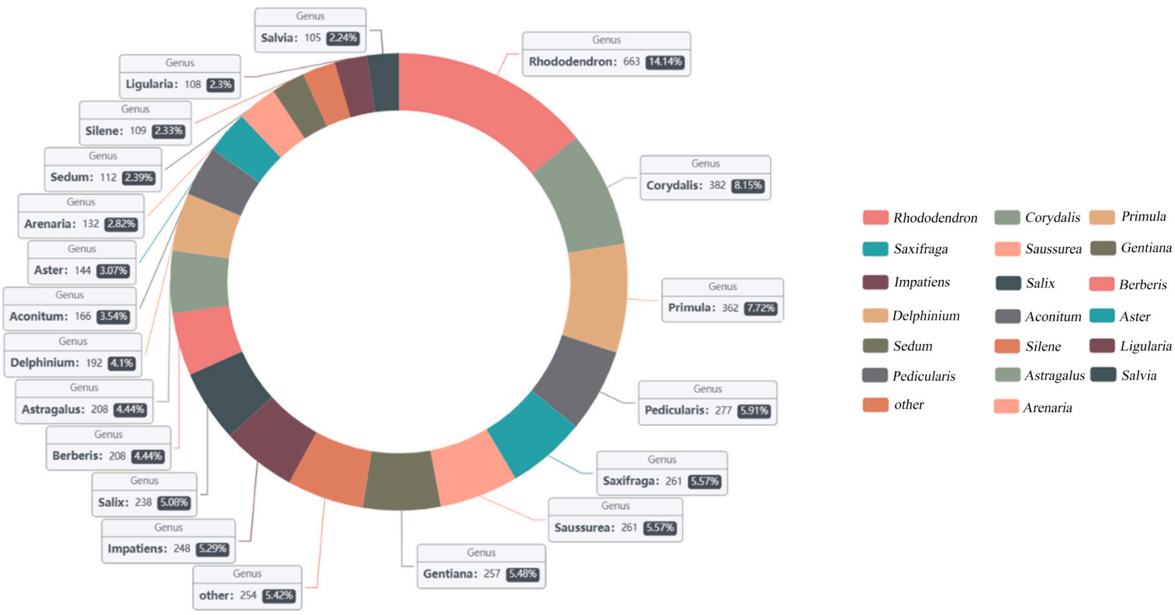


Figure 2. The proportion of more than 200 endemic plant families in the southwestern mountains.

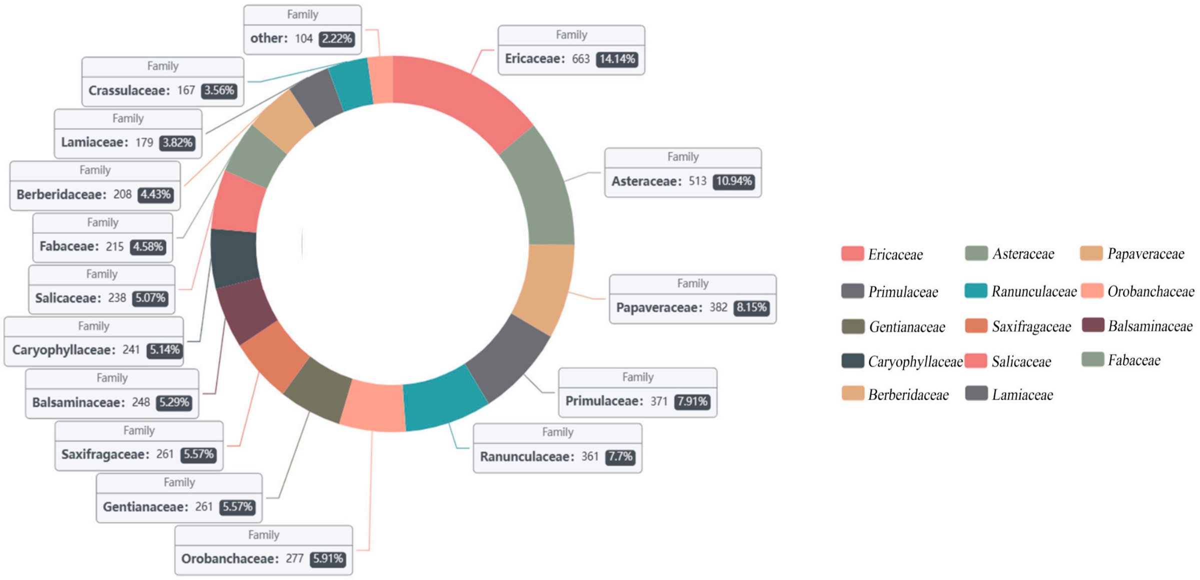


Figure 3. The proportion of more than 100 genera of endemic plants in the southwestern mountains.

3.2. Spatial Distribution Pattern of Endemic Plant Species Richness in Southwest Mountainous Region

The spatial distribution of endemic plants in the southwestern mountains is uneven, with species richness in each grid ranging from 0 to 699 species (Figure 4). It is mainly concentrated in the Heng Duan Mountain area, southwest Sichuan and northern Yunnan area, and the Ruoergay-Hongyuan area of west Sichuan Plateau. The regression analysis of the species richness of endemic genera in the southwest mountain region (Figure 5) shows the following: (1) In the horizontal direction, the species richness of endemic genera in the southwest mountain region is higher in the region of 27.50°–30.00° N, and gradually decreases with the increase in latitude in the north; species richness reaches its maximum in the 98.00°–105.00° E region, and decreases with increasing or decreasing longitude on both the eastern and western sides of this high value range. (2) In the vertical direction, the species richness of endemic genera in the southwest mountainous region increases first and then decreases with the increase in altitude in a single-peak form, with the peak value in the range of 3000–4000 m.

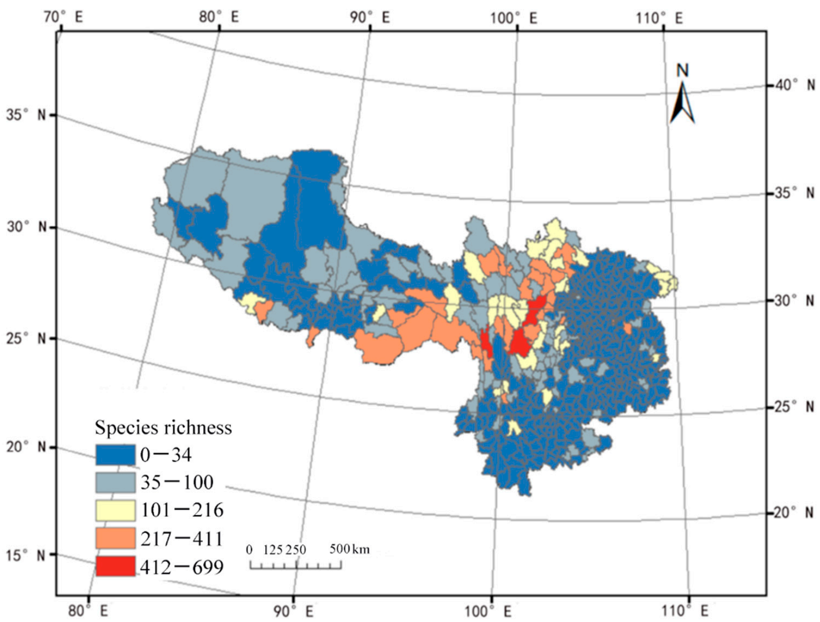


Figure 4. Pattern of endemic plant species richness in the Southwest Mountainous region.

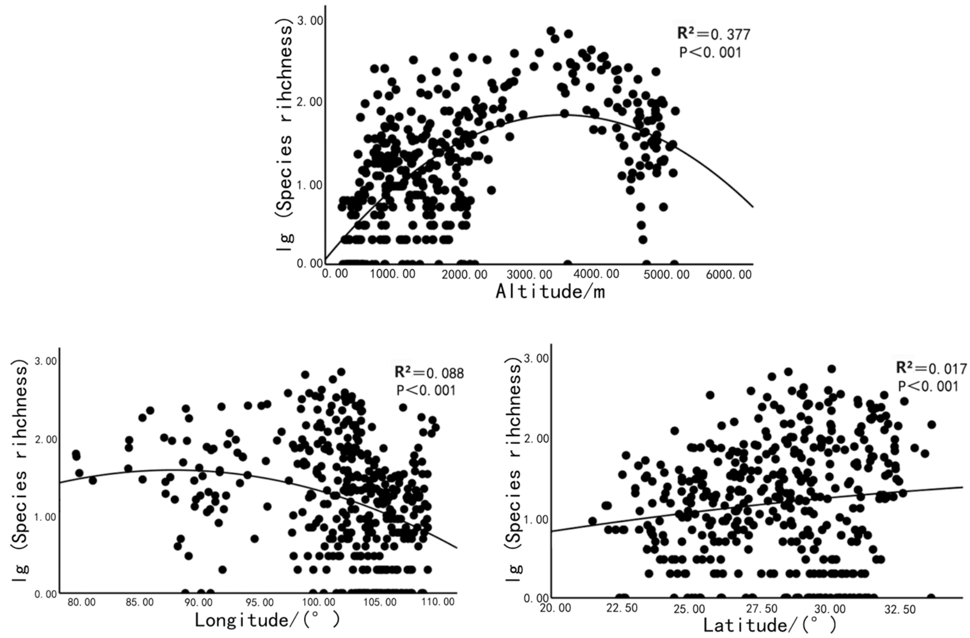


Figure 5. Relationship between the abundance of endemic genera and longitude, latitude, and altitude in the southwest mountainous region.

3.3. GWR Model Results

The ordinary least square (OLS) model analysis, excluding the selection of models with variance inflation factor (VIF) greater than 7.5, yielded three factors: annual average temperature, average diurnal range, and seasonal temperature. There are four water factors, namely precipitation in the wettest month, precipitation in the driest month, precipitation seasonality and precipitation in the coldest season. There are five human disturbance factors: GDP, night lights, distance to the main road, distance to the city center, and distance to the expressway. A GWR geographical weighted regression model was used to analyze the effects of these factors on endemic plants in southwest mountainous areas. The regression results of model parameters are shown in Table 2. It can be seen from the table that the adjusted average diurnal range has the largest R^2 and the smallest AICc value, which proves that in the single factor analysis, the average diurnal range has the greatest impact on the endemic plants in the southwest mountain region, possibly because the diurnal temperature difference is conducive to the accumulation of organic matter and thus to the growth of plants. Among the water factors, the seasonal R^2 of precipitation is the largest, and the seasonal change in precipitation has a great impact on the growth of plants. In the south, precipitation is mostly concentrated in the growing season, forming an obvious phenomenon of rain and heat in the same season, so that precipitation plays a greater ecological role, which is conducive to the growth and development of plants and crops, and has important practical significance for ecological construction and agricultural production. Among the human interference factors, the R^2 distance from the main road is the largest. Along with the economic development, the density of the urban road network gradually increases, and the flow of people and vehicles on the main road also keeps increasing. Within a certain buffer range, different degrees of interference are formed, resulting in different degrees of influence on the growth of plants.

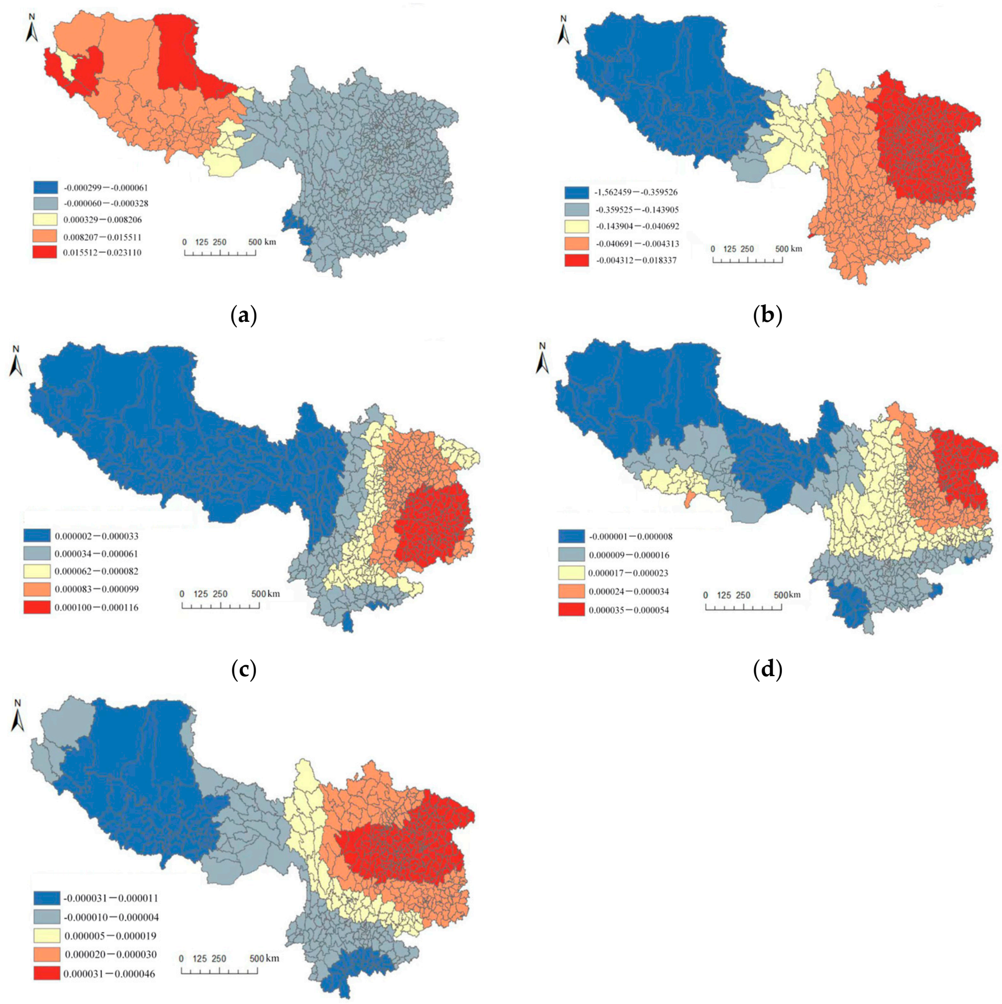
Table 2. GWR model regression results.

Item	Max	Min	Mean	SD	R^2	Adjust R^2	AICc
Species richness	2.84	0	1.17	0.74			
Annual mean temperature/°C	20.82	−7.39	11.57	7.32	0.349	0.309	1038.80
Mean Diurnal Range/°C	14.53	6.26	9.14	2.24	0.484	0.467	898.71
Temperature Seasonality/°C	981.61	335.19	642.53	132.79	0.395	0.372	984.89
Precipitation of Wettest Month/mm	390.31	19.34	191.50	63.15	0.393	0.356	1003.59
Precipitation of Driest Month/mm	34.48	0.23	12.35	7.14	0.369	0.331	1022.14
Precipitation Seasonality/mm	137.25	45.23	82.59	15.57	0.445	0.411	957.43
Precipitation of Coldest Quarter/mm	859.13	1.52	149.76	213.31	0.343	0.305	1041.59
GDP	20,788.07	0.12	470.74	1687.77	0.321	0.288	1051.23
Night Lights	62.61	0	4.99	10.36	0.364	0.332	1019.65
Distance to main road/m	123,260.65	0	6268.36	9888.30	0.465	0.433	936.96
The distance to the city center/m	202,684.63	2774.84	24,511.39	18,231.94	0.460	0.426	944.57
The distance to the expressway/m	2405,78.46	400.30	11,068.48	15,969.96	0.421	0.385	979.01

3.4. Relationship between Endemic Plant Species Richness Pattern and Environment and Human Disturbance in Southwest Mountainous Region

With the deepening of human economic and social activities, human disturbance has an increasingly serious impact on the ecosystem [11]. In recent years, the rapid economic growth of Sichuan, Yunnan, Chongqing and Yunnan has been accompanied by the influx of a large number of people and the increase in population density, which has led to the excessive degree of human disturbance, damage to the original habitat conditions of plants, and breaking the ecological threshold of plant resistance to disturbance. As can be seen from Figure 6a, GDP of the other four provinces except Tibet has a negative impact on the richness. Due to the large geographical area and low population density, appropriate human disturbance can promote plant growth in Tibet to some extent with the increase in GDP. Throughout the southwestern mountains, night light has a negative impact on the abundance of endemic plants (Figure 6b). The main reason is that night light destroys the rhythm of the plant biological clock, and it exerts high radiation energy on plants, which will cause the leaves or stems of plants to change color or even die. However, the distance to the main road, the distance to the expressway and the distance to the city center have a positive impact on the abundance of endemic plants in the southwest mountain region (Figure 6c–e), that is, the distance is conducive to the growth of plants, while the excessive traffic flow and population density exceeding a certain limit are not conducive to the growth of plants, resulting in a decrease in the number of plants.

The seasonal variation of precipitation has a positive effect on the abundance of endemic plants in the southwest mountains, and the intensity of precipitation spread outward from Sichuan and gradually weakened, and the intensity of precipitation was weakest in the Linzhi and Naqu regions of Tibet (Figure 7a). The precipitation in the coldest season had a negative effect on all regions except the Ngari region of Tibet (Figure 7b). In a low-temperature environment, the growth rate of plants was relatively slow and the water demand decreased. The micro-environment where plant roots live had a rapid temperature drop and is prone to frostbite. Due to its geological landform, the Ngari region has a unique climatic feature, with a long winter and short summer and very little annual precipitation, and a certain amount of precipitation is conducive to plant growth. The precipitation in the driest month had a positive impact on the endemic plant richness in the southwest mountain region (Figure 7c), that is, the higher the precipitation in the dry month, the more favorable the plant growth. The precipitation in the wettest month has a negative impact on most areas (Figure 7d). The moisture in the wettest month has been able to meet the growing demand of plants, and the increase in precipitation will lead to puddles and floods, which will make the roots of plants anoxic and inhibit the physiological activities of the roots.



(**e**)

Figure 6. Influence of anthropogenic factors on endemic plant richness pattern in the Southwest Mountainous region. (**a**) Influence of GDP on abundance; (**b**) influence of lighting on richness; (**c**) influence of distance to main road on abundance; (**d**) influence of distance to the city center on abundance; (**e**) influence of distance to expressway on richness.

Average annual temperature has a negative impact on species richness in most areas, and a positive impact on species richness in Shannan City and the Naqu region of Tibet (Figure 8a); average diurnal range has a negative impact on species richness in Tibet, and a positive impact on species richness in other areas (Figure 8b). A large diurnal temperature difference is conducive to plant nutrient accumulation, and plants with high daytime temperature can perform photosynthesis better and accumulate more nutrients. More water and organic matter are produced, and recycling encourages better plant growth. Therefore, the ground receives more solar radiation, the temperature is relatively high, and the thin air at night has a weak effect on the insulation of the ground, and the temperature drops rapidly, resulting in a large temperature difference between day and night. Seasonal temperature changes had a negative effect on species richness in Sichuan and northern Yunnan, and a positive effect on species richness in other areas (Figure 8c), indicating that small seasonal temperature changes in Sichuan and northern Yunnan were beneficial to plant growth.

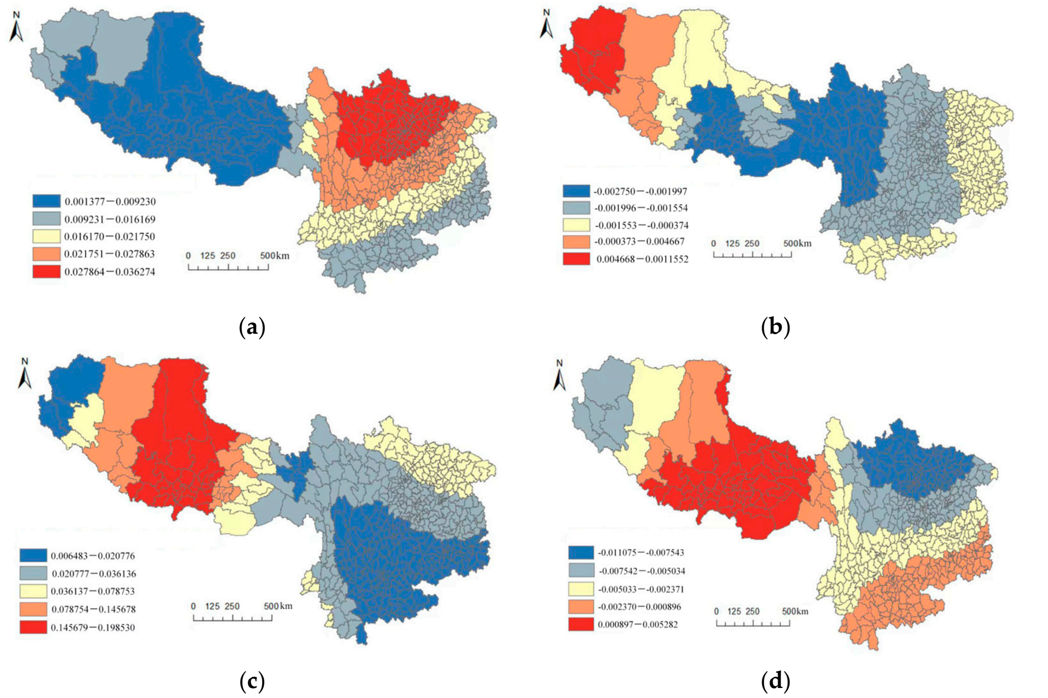


Figure 7. Influence of water factors on the richness pattern of endemic plants in the Southwestern Mountainous region. (**a**) Influence of precipitation seasonality on abundance; (**b**) influence of precipitation on abundance in coldest season; (**c**) influence of precipitation on abundance in driest months; (**d**) influence of precipitation on richness in the wettest months.

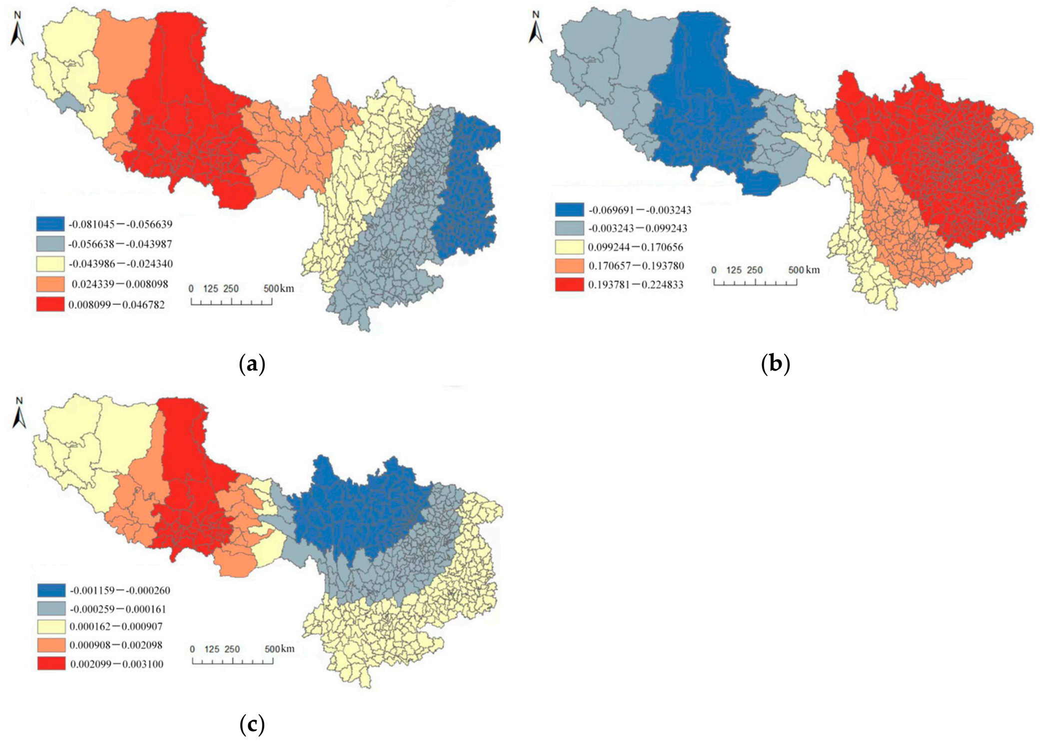


Figure 8. Influence of energy factors on the richness pattern of endemic plants in the Southwestern Mountainous region. (**a**) Influence of annual mean temperature on richness; (**b**) influence of mean diurnal range on abundance; (**c**) influence of temperature seasonality on abundance.

3.5. Effects of Energy, Water and Anthropogenic Disturbance on Endemic Plant Species Richness in Southwestern Mountainous Areas

In order to further explore the impact of energy, water and human disturbance factors on the endemic plant richness in the southwest mountain region, and eliminate the multi-collinearity effect between variables, GWR model analysis was conducted with the endemic plant species richness in the southwest mountain region as the dependent variable and the above three models as the independent variables, respectively (Table 3). The results showed the following: Among the three models, the energy model has the highest explanation rate of the endemic plant species richness in the southwest mountain, reaching 55.4%. The second is the moisture model, the explanation rate is 54.4%; the interpretation rate of moisture model is 46.2%. The distribution pattern of endemic plant species richness in the Southwest Mountainous region is affected by energy, water and human disturbance, among which energy and water play the main roles.

Table 3. Optimal models of endemic plant richness and different influencing factors in the southwest mountainous region.

Model	Impact Factor	R^2/%	*p*
Energy	Annual mean temperature, Temperature seasonality, Mean diurnal range	55.4	<0.001
Water	Precipitation seasonality, Precipitation of wettest month, Precipitation of coldest quarter, Precipitation of Driest Month	54.4	<0.001
Human interference	GDP, Night Lights, Distance to main road, Distance to the city center, The distance to the expressway	46.2	<0.001

4. Discussion

4.1. Characteristics of Plant Richness of Endemic Genera in Southwest Mountainous Region

A total of 4688 endemic plant species belonging to 32 genera and 19 families were investigated in the study area. We identified more than 300 species in 5 families, including *Ranunculaceae*, *Rhododendraceae* and *Compositaceae*, and 3 genera including *Rhododendron*, *Primula* and *Corydalis*. For example, *Pedicularis* and *Saxifraga* contain a large number of endemic species in China [36], most of which are endemic to the southwestern mountains, which is intrinsically related to the fact that southwest China, as a biodiversity hotspot, is the distribution and differentiation center of many taxa [37]. At the subordinate level, *Rhododendrons*, *Corydalis*, *primula*, *pedicularis* and *Saxifraga* all contain more species in the southwestern mountains, among which *Rhododendrons* have the largest number of species. The Heng Duan Mountains is a diversified distribution center of *Rhododendron*. The abundant precipitation, suitable temperature and stable environment in this area promoted the differentiation and formation of *Rhododendron* [38].

4.2. Spatial Distribution Pattern of Endemic Genera in Southwest Mountainous Region

The decline in plant species richness from the equator to the poles is one of the most significant ecological patterns on Earth [39,40]. In the direction of longitude, the species richness of Chinese plant groups generally shows a unimodal relationship, and the peak value is mostly located in the range of 95–110° E [32,33]. Therefore, the southwest Heng Duan Mountains region is the intersectional area of longitude and latitude with the highest plant species richness in China [35,41]. In the vertical direction, with the increase in altitude, the richness of plant species increases first and then decreases, and the vertical distribution pattern of species peaks in the middle altitude area [42,43]. The most active horizontal distribution areas of endemic genera in southwest mountainous areas are mainly the Heng Duan Mountains in southwest China and the mountains around Sichuan Basin, which is consistent with the general law of horizontal distribution of plant species in China. In the vertical direction, the species richness of endemic genera in the southwest mountainous region presents a single-peak form, with the peak value in the range of 3000–4000 m, which is consistent with the general law of species variation with altitude.

The endemic genera in southwest mountainous areas are mainly concentrated in the Heng Duan Mountain area, southwest Sichuan and northern Yunnan area, and Ruoergay-Hongyuan area of west Sichuan Plateau. The Heng Duan Mountain region in southwest China and the mountains around Sichuan Basin are characterized by abundant precipitation, suitable temperature, complex topography, and high habitat heterogeneity [44,45]. Therefore, endemic genus plants in the southwest mountains have higher species richness in areas with good moisture and heat conditions and fewer human disturbance factors [42,46].

At the same time, low-latitude areas in China have better hydrothermal conditions than high-latitude areas, and according to Rapoport's rule, low-latitude areas have stronger climate stability. Compared with plain areas, mountainous areas have more complex topography and higher habitat heterogeneity [47]. Therefore, the southwest mountainous area has a higher species richness distribution than the high-latitude area and the plain area.

4.3. Relationships between Endemic Genus Richness and Environmental Factors Analyzed by GWR Model

The GWR model analysis revealed that the abundance pattern of endemic genera in southwest mountainous areas was significantly correlated with several environmental factors and human disturbance factors. Among the single factors, the average diurnal temperature range, precipitation seasonality and distance from the main road had significant effects on species richness. The comprehensive model showed that energy, water and human disturbance all had high fitting degrees, which were 55.4, 54.4% and 46.2%, respectively. According to the productivity hypothesis, the increase in energy and water will increase the net primary productivity of an area and can increase the accumulation of biomass. As a result, the population size of plants in the region increased, corresponding to higher species richness [48]. In addition, according to the interpretation rate of variance of energy, water and species richness model, water heat is an important driving factor for the species richness and endemic distribution of endemic plants in the southwest mountain region, which means that the modern climatic hydrothermal conditions play a crucial role in the formation of the abundance and spatial distribution pattern of endemic plants in the southwest mountain region. This is consistent with the current research results on the relationship between large-scale distribution patterns of plants and environmental factors [33]. The results show that the distribution pattern of endemic plant richness in the southwest mountainous region is simultaneously affected by multiple factors such as energy, water and human disturbance, and no single environmental factor or hypothesis can fully explain the species richness pattern [30].

5. Conclusions

Based on the distribution data of endemic genera in the southwest mountainous region, combined with the corresponding environmental factors and human disturbance factors, this study discussed the distribution pattern and influencing factors of endemic genera in the southwest mountainous region, and found that it was uneven in the distribution of endemic genera in the southwest mountainous region. High endemic plant abundance, is mainly concentrated in the Heng Duan Mountain, southwest Sichuan and northern Yunnan, West Sichuan Plateau from Ruoergai to Hongyuan area, and vertically concentrated in the middle and high altitude areas. Places with good hydrothermal conditions and less human interference have higher species richness, and the average daily temperature difference, precipitation seasonality, and distance from the main road are the main driving forces affecting the species richness of endemic genera in the southwest mountain region.

Author Contributions: Conceptualization, A.C., T.W. and B.L.; methodology, Z.J.; Software, A.C., D.H. and Z.F.; Validation, Z.J., D.H., D.J. and Z.F.; Formal analysis, D.J. and Y.W.; Investigation, A.C., T.W. and B.L.; Resources, A.C., T.W. and B.L.; Data curation, T.W. and B.L.; Writing—original draft preparation, A.C.; Writing—review and editing, Z.J., H.D, D.J., Y.W. and Z.F.; Visualization, Z.F.; Project administration, Z.F. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Basic Scientific Research Program of Heilongjiang Province (145209319) and the Natural Science Foundation of Heilongjiang Province (LH2021C098).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hu, J.; Feng, X.; Cheng, L.; Jiang, J.; Sharon, G.D. Elevational Patterns of Species Richness, Range and Body Size for Spiny Frogs. *PLoS ONE* **2011**, *6*, e19817. [CrossRef] [PubMed]
2. Pan, X.; Ding, Z.; Hu, Y.; Liang, J.; Wu, Y.; Si, X.; Guo, M.; Hu, H.; Jin, K. Elevational pattern of bird species richness and its causes along a central Himalaya gradient, China. *PeerJ* **2016**, *4*, e2636. [CrossRef] [PubMed]
3. Zu, K.; Wang, Z. Research progress on the response of altitude distribution of mountain species to climate change. *Biodiversity* **2022**, *30*, 15.
4. Fristoe, T.S.; Bleilevens, J.; Kinlock, N.L.; Yang, Q.; Zhang, Z.; Dawson, W.; Essl, F.; Kreft, H.; Pergl, J.; Pyšek, P.; et al. Evolutionary imbalance, climate and human history jointly shape the global biogeography of alien plants. *Nat. Ecol. Evol.* **2023**, *7*, 1633–1644. [CrossRef] [PubMed]
5. Ipek, M.; Ravnjak, T.; Ajna, N. Understorey species distinguish late successional and ancient forests after decades of minimum human intervention: A case study from Slovenia. *For. Ecosyst.* **2023**, *10*, 100096.
6. Faramarzi, M.; Isselstein, J. Assessing the response of rare and common plant species to human induced rangeland degradation at a landscape scale in western Iran. *Land Degrad. Dev.* **2023**, *34*, 5042–5054. [CrossRef]
7. Seipel, T.; Kueffer, C.; Rew, L.J.; Daehler, C.C.; Pauchard, A.; Naylor, B.J.; Alexander, J.M.; Edwards, P.J.; Parks, C.G.; Arevalo, J.R.; et al. Processes at multiple scales affect richness and similarity of non-native plant species in mountains around the world. *Glob. Ecol. Biogeogr.* **2012**, *21*, 236–246. [CrossRef]
8. Costa, F.V.D.; Viana-Júnior, A.B.; Aguilar, R.; Silveira, F.A.; Cornelissen, T.G. Biodiversity and elevation gradients: Insights on sampling biases across worldwide mountains. *J. Biogeogr.* **2023**, *50*, 1879–1889. [CrossRef]
9. Toure, D.; Ge, J.W.; Zhou, J.W. Interactions between Soil Characteristics, Environmental Factors, and Plant Species Abundance: A Case Study in the Karst Mountains of Longhushan Nature Reserve, Southwest China. *J. Mt. Sci.* **2015**, *12*, 943–960. [CrossRef]
10. Fois, M.; Murgia, L.; Bacchetta, G. Plant diversity and species composition of the abandoned mines of the Iglesiente mining district (Sardinia, Italy): A restoration perspective. *Ecol. Eng.* **2023**, *188*, 106879. [CrossRef]
11. Yao, X.; Hao, J.; Qi, J.; Sun, Q.; Yao, J.; Wu, X. Effects of human disturbance on community structure and species diversity of Schima Schima secondary forest in Bifeng Gorge, western Sichuan. *J. Northwest A F Univ.* **2017**, *45*, 18–26.
12. Leley, N.C.; Langat, D.K.; Kisiwa, A.K.; Nzove, B.; Maranga, E.K.; Odadi, W.O.; Koskey, C.C. Recovery Status and Livestock Use of a Kenyan Montane Forest a Decade after Cessation of Human Encroachment. *Ecol. J.* **2023**, *13*, 291–319. [CrossRef]
13. Pagel, J.; Cooksley, H.; Schurr, F.M.; Walter, H.E.; Neu, A.; Schleuning, M. Effects of biotic interactions on plant fecundity depend on spatial and functional structure of communities and time since disturbance. *J. Ecol.* **2023**, *111*, 110–124.
14. Cong, X.; Zhang, Y.; Li, D.; Bai, G. Effects of human disturbance on plant species connectiveness in the middle Qinba Mountains. *Wild Plant Resour. China* **2023**, *42*, 90–96.
15. Kier, G.; Kreft, H.; Lee, T.M.; Jetz, W.; Barthlott, W. A global assessment of endemism and species richness across island and mainland regions. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 9322–9327. [CrossRef] [PubMed]
16. Tian, L.; An, M.; Yang, Y.; Liu, F. Composition characteristics and geographical distribution pattern of national key protected wild plants in Guizhou Province. *J. Plant Resour. Environ.* **2023**, *32*, 83–91.
17. Jewitt, D.; Morris, C.D.; O'Connor, T.G.; Tedder, M.J. Dominant species of mid-elevation grasslands of the uKhahlamba-Drakensberg Park are predicted to be largely immune to climate change. *J. Mt. Sci.* **2023**, *20*, 2468–2486. [CrossRef]
18. Guo, W.; Wang, W. Potential changes in the distribution of Meconopsis in the Qinghai-Tibet Plateau under climate change. *Acta Bot. Sin.* **2023**, *43*, 708–716.
19. Xu, X.; Guan, C.; Lan, S. Species composition and diversity of trees in subtropical evergreen broad-leaved forest in Wuyi Mountain, 2002–2015. *Mol. Plant Breed.* **2023**, *21*, 4151–4157.
20. Qizi, S.R.S.; Burxonovich, D.D.; Kudratovich, K.K.; Iskandarovna, U.Z.; Qizi, O.S.G.; Qizi, N.G.K. Analysis of the Distribution of *Tulipa* fosteriana and *Tulipa* ingens. The Importance of Protecting Wild Plants, in Particular *Tulips* All over the World. *Am. J. Bot.* **2023**, *14*, 613–624.
21. Li, S.; McShea, W.J.; The Great Army of Kings; Shen, X. The southwestern mountains show species diversity. *For. People* **2022**, *3*, 42–45.
22. Fang, J. Exploring the distribution of mountain plant diversity in China. *Biodiversity* **2004**, *12*, 4.
23. Zhang, X.; Zhang, B.; Yao, Y.; Liu, J.; Li, J.; Jiang, Y. Spatial differentiation of plant diversity and its relationship with climaticfactors in Qinba Mountain region. *Nat. Reserve* **2023**, *3*, 104–122.

24. Zhang, F.; Liao, Z.; Pan, K.; Zhang, M.; Zhao, Y.; Zhang, L. Modeling of species richness and endemic distribution patterns of Fagaceae in Southwest China and their environmental interpretation. *J. Appl. Ecol.* **2021**, *32*, 11.
25. He, J.; Zhang, M.; Wang, P.; Wang, S.; Wang, X. Characteristics of extreme drought climate change in Southwest China in recent 50 years. *Acta Geogr. Sin.* **2011**, *66*, 12.
26. Cao, W.; Tao, H.; Kong, B.; Liu, B.; Sun, Y. Automatic recognition of landform in Southwest China based on DEM data segmentation. *Soil Water Conserv. China* **2011**, *3*, 38–41.
27. Peng, X.; Yang, Y.; Yin, Y.; Panthi, S.; Xu, T.; Fu, P.; Ge, S.; Fan, Z. Response of radial growth of *alpine pine* (*Pinus densata*) to climatic factors in Baima Snow Mountain, northwest Yunnan. *Acta Ecol. Sin.* **2023**, *43*, 8884–8893.
28. Sun, H. The significance of ancient Mediterranean retreat and Himalaya-Hengduan Uplift in Himalayan composition and the formation and development of yarn in alpine flora in China. *J. Plant Taxon. Resour.* **2002**, *24*, 273–288.
29. Wang, D. *Special Diversity and Biogeography of Endemic Flora in Hengduan Mountain*; Graduate School of Chinese Academy of Sciences University of Chinese Academy of Sciences: Beijing, China, 2009.
30. Wang, S.; Zhu, Z. Distribution pattern of species richness of Roseus in China and its relationship with environmental factors. *Acta Ecol. Sin.* **2021**, *42*, 209–219.
31. Xu, X.; Dimitrov, D.; Shrestha, N.; Rahbek, C.; Wang, Z.; Jordan, G. A consistent species richness–climate relationship for oaks across the Northern Hemisphere. *Glob. Ecol. Biogeogr.* **2019**, *28*, 1051–1066. [CrossRef]
32. Wang, Y.; Wang, J.; Cui, P.; The Bells Sing; Li, J.; Chu, J. Plant species richness pattern and its relationship with environment in Horqin Sandy land. *J. Plant Sci.* **2018**, *36*, 10.
33. Chen, S.B.; Jiang, G.M.; Ouyang, Z.Y.; Wei-Hua, X.U.; Xiao, Y. Relative importance of water, energy, and heterogeneity in determining regional pteridophyte and seed plant richness in China. *J. Syst. Evol.* **2011**, *49*, 95–107.
34. Li, H.; Li, W.; Yao, X. Spatial and Temporal differentiation of agricultural carbon emission factors based on GWR model. *Sci. Technol. Manag. Res.* **2019**, *39*, 238–245.
35. Zou, D.; Wang, Q.; Luo, A.; Wang, Z. Diversity pattern of Roseaceae and conservation status of resource plants in China. *J. Plant Ecol.* **2019**, *43*, 1–15. [CrossRef]
36. Huang, J.; Ma, K.; Huang, J. Species Diversity Distribution Patterns of Chinese Endemic Seed Plants Based on Geographical Regions. *PLoS ONE* **2017**, *12*, e0170276. [CrossRef]
37. Liu, Q.; Wu, X.; Xing, H.; Chi, K.; Wang, W.; Song, L.; Xing, X. Orchid diversity and distribution pattern in karst forests in eastern Yunnan Province, China. *For. Ecosyst. Engl.* **2023**, *10*, 348–356. [CrossRef]
38. Bao, L.; Wang, N.; Ni, Z.; Lu, T. The influence of the uplift of the Qinghai-Tibet Plateau on the climate of Southwest China: From the perspective of monsoon. *J. Earth Environ.* **2018**, *9*, 11.
39. Colville, J.F.; Beale, C.M.; Forest, F.; Altwegg, R.; Cowling, R.M. Plant richness, turnover and evolutionary diversity track gradients of stability and ecological opportunity in a megadiversity centre. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 20027–20037. [CrossRef] [PubMed]
40. Lind, S. Diversity patterns of ferns along elevation in Andean tropical forests. *Trans. Bot. Soc. Edinb.* **2015**, *8*, 13–24.
41. Zhang, Y.; Du, H.; Jin, X.; Ma, K. Species diversity and geographic distribution of wild orchids in China. *Sci. Bull.* **2015**, *60*, 179–188.
42. Loiola, P.P.; Morellato, L.P.C.; Camargo, M.G.G.; Kamimura, V.A.; Mattos, J.S.; Streher, A.S.; Stradic, S.L. Shared-role of vegetation types, elevation and soil affecting plant diversity in an old-tropical mountain hotspot. *J. Mt. Sci.* **2023**, *20*, 1842–1853. [CrossRef]
43. Campos, C.A.D.A.; Kari, K.; Manuel, V.P.; Viana, N.A. Patterns of species richness and beta diversity of vascular plants along elevation gradient in Brazilian páramo. *J. Mt. Sci.* **2023**, *20*, 1911–1920.
44. Zhang, L.; Liu, X.; Sun, Z.; Bu, W.; Bongers, F.J.; Song, X.; Yang, J.; Sun, Z.; Li, Y.; Li, S. Functional trait space and redundancy of plant communities decrease toward cold temperature at high altitudes in Southwest China. *Sci. China Life Sci. Engl.* **2023**, *66*, 9. [CrossRef] [PubMed]
45. LV, L.; Cai, H.; Yang, Y.; Wang, Z.; Zeng, H. Species diversity patterns of gymnosperms in China and their influencing factors. *Biodiversity* **2018**, *26*, 14.
46. Tyagi, V.; Singh, S.P.; Singh, R.D.; Gumber, S.; Thadani, R.; Pandey, R. Influence of slope position and aspect on the vegetation attributes and treewater relations in forests of the central Himalayas. *J. Mt. Sci.* **2023**, *20*, 2592–2602. [CrossRef]
47. Liu, Y. Spatial Distribution Characteristics of Endemic Woody Seed Plant Species in China and Their Relationship with Environmental Factors. Master's Thesis, Anhui Agricultural University, Anhui, China, 2019.
48. Wu, A.; Deng, X.; Ren, X.; Xiang, W.; Zhang, L.; Ge, R.; Niu, Z.; He, H.; He, L. Spatial distribution pattern of arboreal community species diversity and its influencing factors in a typical forest ecosystem in China. *Acta Ecol. Sin.* **2018**, *38*, 12.