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Species diversity and spatial differentiation of heritage trees in Chengdu, China

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Introduction: Heritage trees have special historical, cultural, and landscape value in cities and are keystone ecological structures for urban areas. However, these trees are threatened by rapid urbanization. To facilitate the conservation and management of such trees, our study investigated ancient trees in Chengdu, which is one of the hotspot of biodiversity and Historical and Cultural cities in Southwest of China.

Methods: The floristic diversity, Shannon-Wiener index (H), spatial pattern, characteristics, dimension, age, and health status of the trees were estimated by using ecological indexes and mathematical statistics.

Results: A total of 9383 heritage trees belonging to 119 species in 20 districts of Chengdu were surveyed. Dujiangyan (DJY) had the largest Shannon-Weiner index (H) (2.63), species count (76), and tree count (1842) and is therefore the most important district for preserving ancient trees. In contrast, Qingyang (QY) had the largest density of trees (120 trees/10 km^2) among the 20 studied districts. In terms of important species, *Phoebe zhennan* (2351) was the dominant species, followed by *Cupressus funebris*, *Ginkgo biloba*, and *Ficus virens*. Akaike information criterion weights and standard deviation ellipse analysis showed that mean annual rainfall is a critical predictor for species distribution and age.

Discussion: Findings from this study suggest that reducing water stress environments will improve the management and conservation of heritage trees in the future.

KEYWORDS

ancient trees, floristic diversity, mean annual rainfall, tree conservation, urban tree

1 Introduction

Large heritage trees are keystone ecological features that play crucial roles in maintaining the structure and dynamics of natural communities (Lindenmayer et al., 2014; Stephenson et al., 2014). Firstly, these trees included high values of biodiversity conservation and ecosystem function. For instance, the tree rings in ancient trees provide crucial information about changes in climate spanning several thousand years. This data is essential for accurately reconstructing past climatic conditions (Yang et al., 2014). Old trees not only play a significant role as reservoirs of genetic diversity and often exhibit high reproductive fitness. (Hanlon et al., 2019; Mosseler et al., 2002), but also are linchpin in nutrient cycling (Lindenmayer and Laurance, 2016), carbon storage (Fedrigo et al., 2014; Sist et al.,2014) and as biological legacies (Manning et al., 2006, 2009). Secondly, they also have high cultural and aesthetic values (Blicharska and Mikusiński, 2014; Lindenmayer and Laurance, 2017). As is well known, it is due to their cultural importance in religions and sacred practices (e.g., where children were born and people are buried)(Blicharska & Mikusiński, 2014; Lindenmayer and Laurance, 2017). Furthermore, during the rapid urbanization cities, the abundance of ancient trees, which are a surrogate icon of nature in cities, reflect the historic processes of urbanization (Jim, 2004). Thirdly, Most heritage trees have ornamental value, such as *Ginkgo biloba*, whose spectacular golden foliage in the autumn attracts visitors and tour groups; *Osmanthus fragrans* contains a fascinating aroma when it blossoms; and *Lagerstroemia indica* is commonly used as an ornamental species owing to its attractive flower color. Additionally, the high cultural value of heritage trees has been well documented (Chen and Hua, 2017) as these trees, which are connected with ancient tales and silvertail, have witnessed the vicissitudes of city citizenry and fabric and are regarded as mascots for people (Aird, 2005).

Chengdu, a city with abundant biological diversity in southwest China, has developed markedly in recent decades. Part of Chengdu belongs to the Rainy Zone of West China (Xiang et al., 2017), which is renowned for its beautiful landscapes, plentiful vegetation types, abundant resources, and diversity of plants and animals (Zhuang and Gao, 2002). Therefore massive heritage trees exit in Chengdu. On the other hand, different plant species have varying adaptabilities to their environments. For example, *Phoebe zhennan* prefers moist conditions, whereas *Ficus virens* is more drought-tolerant and can grow in various soil condition. As a historic city, Chengdu has numerous scenic spots, including Lidui Park, Xiling Snow Mountain, Shijing Temple, and so forth, many of which contain heritage trees (Figure 1), and abundance of heritage trees are protected in these places of Chengdu. Human activities such as planting, providing water, and managing diseases have been shown in various studies to have a favorable impact on the abundance and well-being of mature, sizable tree populations (Hartel et al., 2018; Lindenmayer et al., 2016; Wan et al., 2020; Min and Wang, 1994). Conversely, during the past 40 years, the GDP of Chengdu has sharply ascended by 554-fold, and the population has expanded from 8.06 million to 15.20 million. Rapid and sustained urbanization may dramatically alter the ecosystem functions of cities (Chen et al., 2022; Li and Zhang, 2021). Several studies have clarified t negative human influences on heritage trees. Many populations of large old trees are declining as a result of logging, human-induced climate change, habitat loss and fragmentation (Bennett et al., 2015; Laurance et al., 2000; Lindenmayer et al., 2012).

In recent years, there has been increasing scientific research in China on heritage trees, with diverse themes including tree-age evaluation (Chao et al., 2005; Xu and Zheng, 2013) and health and disease (Liu and Xu, 2013; Sun, 2012). Information and methods from these studies could be applied for the protection and stewardship of ancient trees in Chengdu. Furthermore, effective conservation of very old trees requires a basic understanding of their regional distribution patterns and driving factors (Liu et al., 2022; Xie et al., 2022; Fu, 2013; Bao et al., 2009; Huang et al., 2015; Tian et al., 2014). It is universally acknowledged that the species composition and distribution patterns of heritage trees are usually affected by a combination of factors, such as natural environment, local customs, religious beliefs, historical changes and economic development (Chi et al., 2020; Xie et al., 2022). Current researches on heritage trees have been conducted the species diversity of old trees at the regional level, including Beijing, Changchun, Sanya and other cities in China (Chen, 2010; Yang et al., 2022; Liu et al., 2013). Their divergence of species diversity and spatial pattern is notable

FIGURE 1
Photographs of heritage trees in scenic spots of Chengdu.

by geographical regions, management measures, and urban development patterns (Zhang et al., 2017). However, species diversity and spatial distribution has not yet been quantified in Chengdu belongs to Mountains of Southwest China, which is one of 36 global biodiversity hotpots. This knowledge gap is crucial for the practical conservation of these trees. Consequently, understanding the key factors circumscribing the distribution of heritage trees from a Chengdu is conducive to formulating conservation strategies from a macroscopic perspective.

In order to comprehend what determines the persistence of heritage trees in Chengdu, this present study aimed to analyze the spatial distribution and species composition of heritage trees in Chengdu, which contains 20 administrative districts and is a national central city. More specifically we are pursuing following key goals:(a) To provide a descriptive overview over the size distribution and abundance of heritage trees in Chengdu City, 119 species were planted in different districts of Chengdu at least 100 years ago.; and (b) To explore key environment and anthropogenic variables influence spatial patterns of these trees. We using quantitative plant ecology and statistical techniques to examine following predictions: (i) Districts with ample rainfall is characterized by both a higher diversity and counts of heritage old trees, and 100 oldest trees associate with regions where is abundant annual rainfall as well. (ii) The changes in rainfall patterns have influenced the response of ancient tree species in Chengdu to the environment. The dominant plants distributed in areas with less rainfall exhibit stronger drought resistance. (iii) There are regional divergence in the dominant of heritage trees in Chengdu city because of historical differences in development and management of ancient government model. And, (iv) Anthropogenic variables have both negative and positive effects on growth status of heritage trees.

2 Study area and methods

2.1 Study area

Established as a capital of Sichuan province over 2000 years ago, Chengdu is situated in southwest China at 30°05′–31°26′ N and 102° 54′–104°53′ E, lying in the central hinterland of Sichuan basin. Chengdu borders Deyang city in the north and Meishan city in the south and the Jinjiang river runs through the city. Chengdu has unique climate characteristics—being hot-wet in summer and dry-warm in winter—resulting from its subtropical humid climate; in 2020, the mean annual precipitation was approximately 946.8 mm, the mean air temperature was 16.8°C, and the annual sunshine duration was 939.3 h (Statistical Bureau of Sichuan and NBS Survey Office in Sichuan, 2022; Wu, 2019). The major landforms of Chengdu are complex, consisting of hills in the east, plains in the middle and mountains in the west, and the elevations are between 359 m to 5364 m. The megacity, comprising 20 administrative districts, covers 14,335 km^2 of land and supported a registered population of more than 15 million in 2021 (Statistic Bureau of Chengdu and NBS Survey Office in Chengdu, 2022). Key information for the 20 administrative districts of Chengdu is summarized in Table 1 (Statistic Bureau of Chengdu and NBS Survey Office in Chengdu, 2022).

2.2 Methods

2.2.1 Defining ancient trees

It is a challenge to precisely define ancient trees (Lindenmayer and Laurance, 2017). This study followed the *Technical Guidelines for Document Establishment of General Survey of National Ancient-Famous Trees* (Huang et al., 2015; Lin and Tang, 2012; Liu et al., 2019), which was issued by the State Forestry Bureau of China in 2001. Therefore, trees ≥100 years old were defined as ancient trees and were then sorted into three protection categories: tier 1, ≥500 years old; tier 2, 300–499 years old; and tier 3, 100–299 years old. In this study, ancient trees, old trees and heritage trees refer to the same concept.

2.2.2 Data survey

According to local laws, the age of ancient trees could not be assessed by any instruments that might harm the trees, even though some of these instruments generate precise data. Hence, the age of trees was assessed predominantly by oral history of local people and references in historical and village records. In 2020, We were involved in assessing heritage trees. The coordinates, diameter at breast height (DBH), photos, height, growth status, age of the trees were recorded and collated by GPS, diameter ruler, single-lens reflex (SLR) camera, and TruPulse 200 laser rangefinder. Beginning with identification of tree species, morphological characteristics were observed, and veteran biological traits characteristic of tree species followed the *Flora of China* (Flora of China Editorial Committee, 2013). Next, the trees were divided into four categories, described as 'good', 'fair', 'poor', and 'dying' (Supplementary Table S1), based on estimation of their growth status (Li and Zhang, 2021; Zhang et al., 2017). Finally, the habitat of each surveyed tree was observed and categorized as urbanization area, rural area, wild area, or scenic spot.

2.2.3 Data analysis

Numerical indices that had been applied in urban-forestry research and vegetation ecology were selected for adoption in this study (Zhang et al., 2017). The flora data of Chengdu city were analyzed by succinct metrics that could characterize the pertinent aspects of species composition, diversity, and evenness. Species diversity of the heritage trees was represented by Shannon-Wiener index (H) (Shannon and Weaver, 1963), which was calculated as $-\Sigma pi\ (\ln pi)$, where pi refers to the proportion of individuals in the sample. A higher value of H indicates a richer and more complex composition of species in the region. We also use Hill number to evaluated species diversity(N0=S,where S was the total number of species; $N1=e^H$, where H represent Shannon-Wiener index; and N2 = 1/D, where D was the Simpson index). The evenness index (J) (Pielou, 1966) was calculated by H/lnS, Relative abundance (RA) and relative dominance (RD) were used to analyze the species Importance Value (IV) (Kuchler et al., 1976) via the equation IV = (RA + RD) × 100/2, in which RA = number of trees in a species/total number of trees in the study area, and RD = basal area at breast height in a species/total basal area in the study area. Five predictors were selected—annual GDP per capita, human population density, land area, mean annual rainfall (MAR), and mean annual

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TABLE 1 Land area, population density, and GDP per capita in 2021 of 20 districts in Chengdu.

District	Abbreviation	Land area (km^2)	Registered population density (person/km^2)	GDP per capita ($)
Chenghua	CH	108	7441	20045
Chongzhou	CZ	1089	604	9006
Dayi	DY	1284	395	8662
Dujiangyan	DJY	1208	514	10393
Jianyang	JY	2214	678	5367
Jinjiang	JJ	61	10357	26480
Jinniu	JN	108	7113	25275
Jintang	JT	1156	780	7597
Longquanyi	LQY	556	1367	26040
Pengzhou	PZ	1421	560	9317
Pidu	PD	437	1541	26743
Pujiang	PJ	580	460	9751
Qingbaijiang	QBJ	379	1116	19295
Qingyang	QY	66	11111	25979
Qionglai	QL	1377	472	7882
Shuangliu	SL	1068	1338	16473
Wenjiang	WJ	276	1918	17205
Wuhou	WH	122	11422	31062
Xindu	XD	496	1680	15385
Xinjin	XJ	329	970	18324
Total or Average	–	14335	1060	17021

temperature (MAT)—to test multi-collinearity by using variance inflation factors (VIF) in this study, and substantial collinearity was not found among the five predictors. The strength of the explanatory variables was evaluated by using a model averaging approach based on the Akaike Information Criterion (AIC) weights. Data were analyzed with Microsoft Excel, and R (Team R Core, 2014). We employed the 'ggplot2' package (from R) and ArcGIS software to generate graphical outputs.

3 Results

3.1 General species composition and dominant species

In the study area, there were 9383 heritage trees derived from 119 species belonging to 91 genera. Among the 43 families of these ancient trees, Lauraceae represented the largest proportion of the data at 33.68%, followed by Cupressaceae and Ginkgoaceae with 21.68% and 18.84%, respectively; the other families lagged behind, forming 0.01% to 6.75% of the data (Figure 2, Supplementary Table S2). Based on counts, the 119 species were grouped into four categories: dominant (>100 trees per species), common (10–100 trees), rare (2–9 trees), and solitary (1 tree). Regarding this disparity, we believe there are two main reasons. First, the species that are abundant are well-suited to the local climate and are favored by people, resulting in a larger number of ancient trees being preserved. Second, most of these abundant species are trees with inherently long lifespans, whereas some shrubs have shorter lifespans, leading to relatively fewer preserved individuals. Three species, namely *Phoebe zhennan*, *Cupressus funebris*, and *Ginkgo biloba*, were dominant species; each of them had more than 1700 individuals, with a total RA of approximately 66.6%. The category defined as common (10–100 trees) comprised 33 identified species and accounted for 13.32% of the total data (Supplementary Table S3). In terms of species IV, of which high values reflect the considerable importance of the species in the community, *Phoebe zhennan* dominated with a higher IV (23.21) compared with those of *Ginkgo biloba* (19.83), *Ficus virens* (18.22), and *Cupressus funebris* (14.55). There were 114 species with an IV <4, and 110 of them had an IV <1 (Supplementary Table S4).

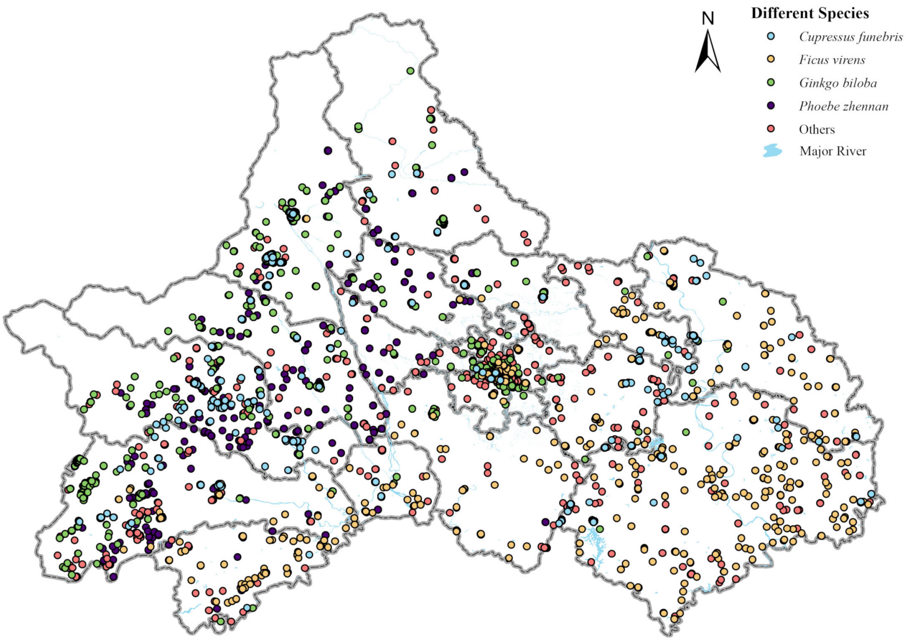

FIGURE 2
Spatial distribution of heritage trees in 20 administrative districts of Chengdu.

3.2 Tree dimensions and differentiation in districts

The distribution of heritage trees was highly unequal among the 20 administrative districts (Table 2). More than 40% of the trees were in three districts located west of Chengdu. All trees in the survey were present for decades to centuries, even to millennia, and thus achieved large dimensions. Dayi (DY) and Dujiangyan (DJY) were the districts with the largest mean tree height, with 22.83 and 22.29 m, respectively. In terms of mean crown diameter, Pujiang (PJ) and Wenjiang(WJ), beyond 15 meters, are higher than others districts. Overall, the Table 2 mirror that basic characteristics of heritage trees in 20 districts

Among all species of ancient trees in Chengdu, there were few overlaps in the 20 districts (Figure 3). This finding is possibly related to anthropogenic factors, such as history, specific situations, and development policy. The Shannon-Wiener index for each of the 20 districts ranged from 1.06 to 2.61, with a mean of 1.67, and the top three districts were DJY (H = 2.61), Longquanyi (LQY) (H = 2.43), and Chneghua (CH) (H = 2.33) (Table 2). However, there were marked differences in the density of trees among the districts. Qingyang(QY) had the largest heritage tree density at 120 trees/10 km^2, which was 120-fold greater than that of Shuangliu(SL), the district with the minimum density of heritage trees.

Regression analyses demonstrated that MAR is a dominant variable that influences the pattern of species count, followed by land area with a weak effect (Variables Importance Value = 0.45). Tree count was obviously affected by land area (VIV = 0.8) and MAR (VIV = 0.76). There was a positive relationship between species count and MAR (r = 0.533, n = 20, p <0.05) and between tree count and land area (r = 0.489, n = 20, p <0.05) (Figure 4). MAR is possibly a key factor for species diversity of ancient trees of Chengdu (as shown by the Variables Importance Value).

3.3 Distribution of heritage trees based on age

Figure 5A shows the estimated spatial differentiation of the oldest 100 trees. According to standard deviation ellipse (SDE) analysis, most of the oldest trees, which have a direction distribution from southwest to northeast, are located in the west of the study area, close to the higher elevation sector of Chengdu. In addition, there was significant variation in the number of trees across different tiers within each district, with tier 3 (constituting 90.7% of all heritage trees) being the predominant category among the three tiers. In terms of number of tier 3 trees, DJY (1640 trees) had the largest count, followed by DY (1269 trees); the other districts had comparatively minimal counts, ranging from 59 to 842 (Figure 5B, Supplementary Table S5).

The health conditions of ancient trees exhibited differences among the four habitats of Chengdu, which were urbanization, rural, scenic spots, and wild. The relationship and variation between four growth statuses, four habitats, and 20 districts is shown in Figure 6 and Supplementary Table S6. For growth status, 'good' represented the largest percentage of heritage trees, at 94.39%; the other statuses lagged behind with 0.01% to 4.99% (Supplementary Table S6). In terms of habitat, most heritage trees dwell in urbanization (3899 trees), followed by rural (2571 trees), whereas scenic spots and wild had comparatively fewer trees, with 1409 and 1504, respectively (Supplementary Table S7). Nevertheless, scenic spots do contribute significantly to the preservation of heritage trees because they are unique habitats with an absence of poor trees (Figure 6).

TABLE 2 Diversity index (H) and evenness index (J) of 20 administrative districts in Chengdu.

District	Tree count	Species count	Mean height (m)	Mean basal area (m2)	Mean crown diameter (m)	Density (tree/10 km^2)	Diversity index (H)	Evenness index (J)
Chenghua	60	16	14.18	0.39	6.55	6	2.33	0.84
Chongzhou	754	22	20.89	0.33	9.67	7	1.36	0.44
Dayi	1368	27	22.83	0.25	7.89	11	1.12	0.34
Dujiangyan	1842	76	22.29	0.36	9.66	15	2.61	0.60
Jianyang	877	20	14.46	0.53	7.03	4	1.33	0.44
Jinjiang	200	15	17.79	0.33	6.20	33	1.10	0.41
Jinniu	168	18	17.25	0.25	8.57	16	1.76	0.61
Jintang	177	13	15.22	0.93	11.29	2	1.58	0.62
Longquanyi	197	22	17.25	0.52	12.07	4	2.43	0.78
Pengzhou	257	17	21.35	0.32	10.90	2	1.86	0.66
Pidu	164	10	16.79	0.32	7.49	4	1.14	0.50
Pujiang	105	13	17.63	1.96	15.73	2	1.37	0.53
Qingbaijiang	66	12	14.82	0.88	12.78	2	1.77	0.71
Qingyang	790	29	19.57	0.32	11.07	120	1.73	0.51
Qionglai	897	27	21.18	0.48	11.12	7	1.77	0.54
Shuangliu	99	12	15.96	1.30	12.61	1	1.90	0.76
Wenjiang	90	9	19.57	0.26	15.33	3	1.06	0.48
Wuhou	495	21	17.10	0.36	11.54	41	1.79	0.59
Xindu	455	18	17.91	0.23	9.04	9	1.76	0.61
Xinjin	322	14	19.42	0.33	9.39	10	1.33	0.50
Total	9383	119	–	–	–	7	–	–

4 Discussion

There are a few researches which focus on species diversity, partial differentiation, urban environments, agricultural landscapes and other non-forested areas in different region around the world (Zhang and Yang, 2020; Liu et al., 2020; Dai et al., 2020; Zhang et al., 2017; Gibbons et al., 2008; Orłowski and Nowak, 2007; Hartel et al., 2018). Our research conducted analysis of the diversity and spatial distribution of ancient trees in Chengdu, which filling the gap in study of heritage trees in Chengdu.And, this study shows that Chengdu supports 9383 ancient trees (>100 years old), *Phoebe zhennan* is the dominant species, and there are some extremely old trees, including individuals approximately 2000 years old, with the age predominantly derived from historical archives rather than dendrochronological dates. Heritage trees are an irreplaceable constitution of the urban landscape, a symbol of an ecological city, and an accompaniment of urban development. The tree-ring characteristics of these trees can reflect the extreme events experienced in the area, namely insect infestation and drought (Li et al., 2021). Ancient trees may support and associate with progress of city development. Moreover, analysis and protection of ancient trees is a crucial mission for Chengdu, which has been constructing the demonstration zone of Park-city—a sustainable development—since 2018.

4.1 Characteristics of heritage trees resources in Chengdu

Various indexes, including counts, species, density, Shannon-Wiener index, were applied in this study to evaluate the diversity of ancient trees in Chengdu (Huang et al., 2020; Orłowski and Nowak, 2007). In terms of species composition, as a representative rapidly urbanized megalopolis, Chengdu has an abundance of ancient trees belonging to 119 species. The numbers for counts and species of heritage trees in Chengdu are greater than those of similar metropolises, such as Guangzhou (384 trees, 25 species) (Jim, 2004) and Changchun (775 trees, 25 species) (Yang et al., 2022), and even Jiangsu Province (7678 trees) (Li and Zhang, 2021). Many trees were preserved in Chengdu owing to its advantageous location and lack of long total war period (Chengdu Chronicles). Moreover, the differences in diversity and evenness of ancient trees among the 20 administrative districts of Chengdu are likely due to the individual landform conditions, urban fabric, and history of urban development in the districts. DJY district had the most species of heritage trees (76 species), while WJ district only had 9 species. On the other hand, DJY, DY and QL have a relatively similar structure in terms of the number and variety of ancient trees, as these three areas are all

FIGURE 3
Heatmap of species distribution of heritage trees in 20 administrative districts of Chengdu. The darker the color, the greater the number of tree count.

located in the Longmen Mountain Range and have comparatively similar climatic conditions. Additionally, these areas share a similar cultural background and are home to numerous scenic spots. Totally, DJY is a critical district in this study, in that it possesses the most heritage trees and the largest H value, tree count and species. Furthermore, there are 27 heritage trees of oldest 100 trees and 41 tier1-trees in DJY as well. There are two explanations were considered: firstly, scenic spots galore were located in DJY; and secondly, splendid irrigation also benefit for existence of abundant heritage trees.

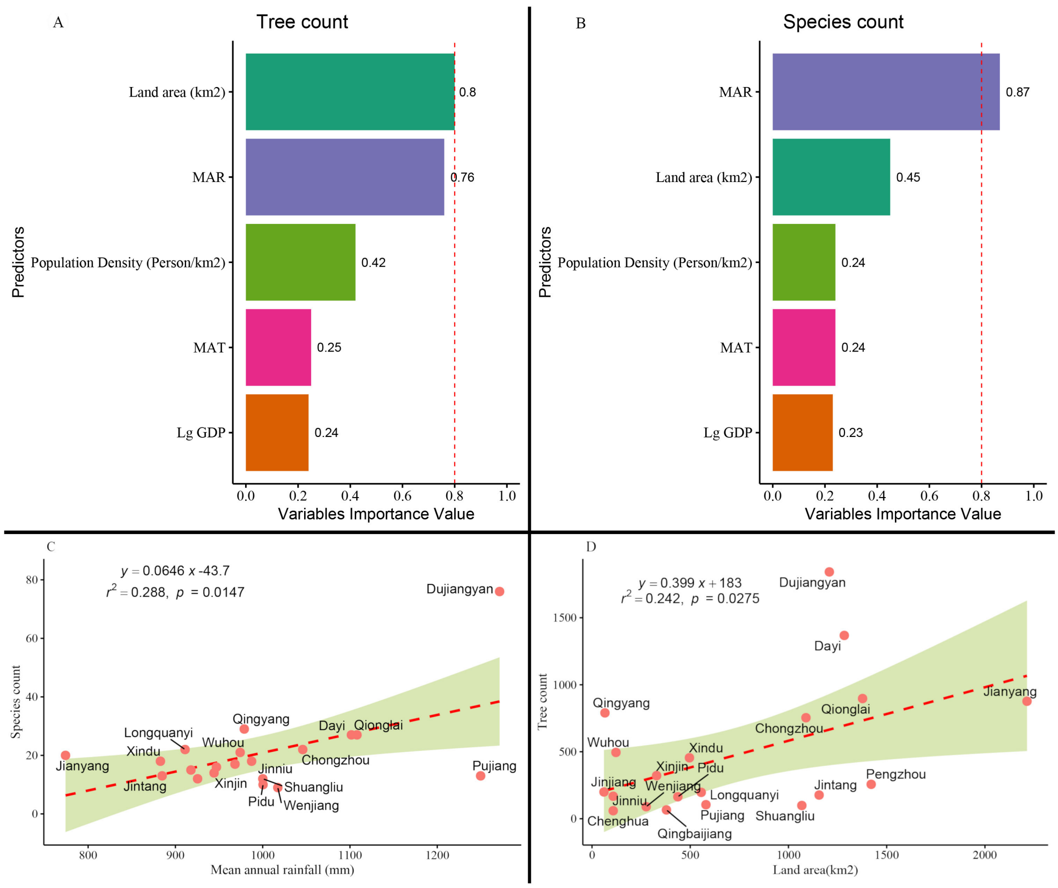

FIGURE 4
Importance value (representing the sum of the AIC-weights of the models in which the variable was present; 1 represents the best predictor) and key predictor of explanatory variables. **(A)** AIC-weights for response variable of tree count; **(B)** AIC-weights for response variable of species count; **(C)** key determinants for the species count; **(D)** key determinants for the tree count.

The large contingent of 9383 heritage trees in Chengdu, dominated by endemic species, indicates a rather rich natural endowment for the municipality. Despite the establishment of a city with a population of approximately 15 million within merely four decades, a respectable number of outstanding trees has been bequeathed to and retained in the urbanized areas. The local government has formulated a series of policies and redevelopment plans, which support sufficient interstitial space for growing heritage trees, to protect the diversity of ancient trees. Urban trees, which were planted in cities in China several thousand years ago, are one of the current important landscaping components (Du et al., 1986). Notably, not only are there wide variations of tree count among the 20 administrative districts of Chengdu but there are also obvious differences in major tree species. This is not only because of the diversity of species in each district itself but also because local governments have certain differences in the planting and preferences of tree species for urban applications.

Phoebe zhennan was the dominant species of heritage tree, with a wide distribution in 15 districts of Chengdu, which is attributed to it being native to Sichuan Province. *Phoebe. zhennan* has a long history of cultivation in Sichuan and has been the exclusive prized timber for royalty since historical times. Moreover, Lauraceae, with 11 species detected, was the dominant and most diverse family of heritage trees in Chengdu. Comparably, *Ginkgo biloba*, which has prominent cultural value, is the only relic plant in the top four species. For example, one Ginkgo called 'Taoist master Ginkgo' is located in Mount Qingcheng and was reportedly planted by Zhang Taoist master who built the Daoist sect. Furthermore, *Ficus virens* is a critical species that can withstand abuses and mistreatment such as construction activities and pest and disease infestation (Jim and Zhang, 2013). These key species planted in Chengdu can satisfy the shelter and food needs of wildlife to provide significant ecosystem services. To our knowledge, this study is the first evaluation of the species diversity of ancient trees in Chengdu by a scientific and unified method. Thus, findings from the study offer a baseline for the protection of ancient trees in Chengdu and provide a scientific reference for heritage tree investigations in other cities.

According to the literature, ecological services should be associated with the dimensions of heritage trees. For instance, larger trees can remove 60–70 times more atmospheric contamination, store and sequester individually 1000 and 90 times more carbon than smaller trees (McPherson et al., 1995). In addition, canopy shading can affect ascension of the cooling effect (Shashua-Bar et al., 2010). The overall net benefit of trees was quantified at \$5–\$9 for a small tree, \$36–\$52 for a medium tree, and

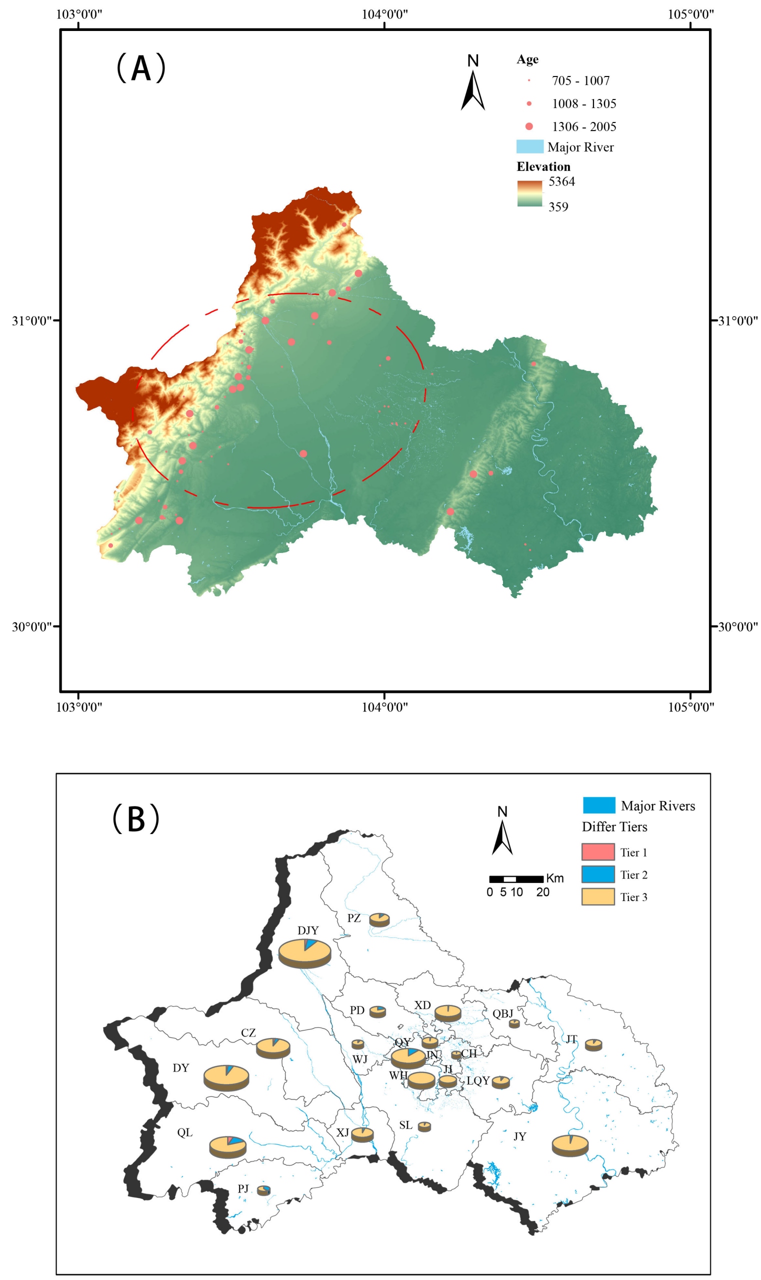

FIGURE 5
Distribution of heritage trees based on age. **(A)** Spatial differentiation of oldest 100 trees; **(B)** proportion of tiers in 20 administrative districts of Chengdu.

\$85–\$113 for a large tree in New York City (McPherson et al., 2007). When it comes to the protection of ancient trees in Chengdu, larger trees have greater ecological value, therefore, we need to provide more protection measures for these larger trees.

4.2 Key environmental variables of heritage trees

Consistent with the plant distribution patterns found in natural environments (Slik et al., 2013; Vandekerkhove et al., 2018), our study—which is congruent with the results of other studies (Liu et al., 2019)—clarified that MAR is a remarkable predictor of the spatial pattern of species. Additionally, partial species are more susceptible to environmental variables, namely, *Phoebe zhennan*. Most of them distributed in west of Chengdu, which has a humid climate and well-developed irrigation systems. Old trees require abundant precipitation to prevent desiccation and maintain tree survival (Choat et al., 2018; Venter et al., 2017), and ancient trees are particularly vulnerable to increasing drought (Bennett et al., 2015). Such situations have occurred around the world, for example, in California of United States and the Central

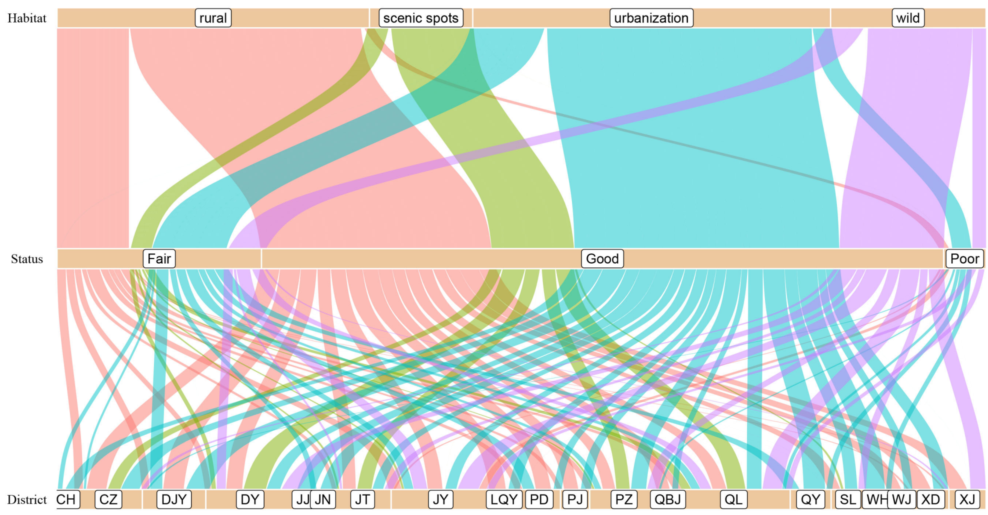

FIGURE 6
Relationship between growth status, habitats, and districts. Log 10 transformation was applied to the counts of trees to facilitate analysis, then dying trees were removed; there was only one dying tree in this study.

Amazon of Brazil, large old trees declined by up to 50% because of water stress and desiccation (McIntyre et al., 2015; Laurance et al., 2000). In addition, water deficiency is a key threat to limiting tree mortality. Old trees were found to have relatively stable growth rates compared with young trees, showing their remarkable resistance to climate warming (Colangelo et al., 2021). However, old trees had higher mortality rates compared with those of smaller trees during climate-change-induced drought (Zhang et al., 2014). In this study, as shown in Figure 5A, the spatial center of the oldest 100 trees was located in the Rainy Zone of West China, which has abundant rainfall. Furthermore, the key factor affecting the distribution of the oldest trees is MAR. For example, the tallest trees in the world are located in regions associated with prolonged periods of fog and/or high precipitation (Larjavaara, 2014).

Several studies have shown that anthropogenic variables are important drivers of spatial pattern and species diversity in large heritage trees (Lindenmayer and Laurance, 2017; Zhang et al., 2017). Nevertheless, inclusion of anthropogenic variables such as the rate of local GDP growth and population growth could not improve the fit of our model. Further research on anthropogenic influences on ancient trees in Chengdu municipality is needed.

5 Conclusion: management implications for conservation

This study analyzed the relationships of environmental and anthropogenic variables on ancient trees in Chengdu, using statistical and geographic information system (GIS) techniques. An understanding of various factors, namely, MAR and land area, could shed light on the history of city–tree interplay and nature conservation in the city. Such findings may provide clues to improve the protection of native trees, especially when such old trees are under stress. Furthermore, conservation of large old trees, especially those set aside for scenic spots, should receive more attention from policy makers and resource managers (Lindenmayer et al., 2013). The ancient trees located in scenic spots have more historical, cultural, and landscape value than the ancient trees in other habitats, and through the data shown in Figure 5, we infer that the administrators of scenic spots have performed excellently in the protection of heritage trees.

This study revealed some important implications for conservation management that could be adopted for local government and citizens. First, conservation projects often receive limited interest from the public (Balding and Williams, 2016). The government needs to steer natives to be more aware of the historical, cultural, and landscape merits of heritage trees, so these residents are more willing to devote resources for the protection of such trees, this could be achieved by disseminating the benefits of heritage trees. Indeed, ancient trees should be considered as a conservation symbol for plant conservation (Lindenmayer and Laurance, 2017). Like many historical monuments, heritage trees represent a link between the city's past and the present and offer a collective memory of society, which refers to the shared pool of memories, knowledge and information of a social group that is significantly associated with the group's identity (Lai et al., 2019). Second, for Chengdu city, which is a rapidly-urbanizing city, should control urban haphazard sprawl, and renewal interface on built-up areas. It means that. Third, a special fund and suitable management model should be established. This study shows the dominant natural environmental variable affecting heritage trees is MAR, which represents the water situation.

Therefore, the conservation of ancient trees requires not only those old trees, but also the soil humidity of niches in Chengdu.

Current ordinance and management systems pay limited attention to environmental variables. Consequently, future conservation policies should consider whether the trees are short of water, especially in years with low rainfall. In addition, funding shortages negatively impact conservation sustainability of ancient trees. Therefore, it may be wise for the fast-developing city of Chengdu to acquire these beneficial practices (monitoring water shortages, steering local people to be more aware of the merits of heritage trees, etc.) now rather than postponing them.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

YY: Conceptualization, Formal analysis, Software, Writing – original draft. SS: Writing – review & editing. FL: Investigation, Writing – review & editing. YX: Investigation, Writing – review & editing. ZJ: Investigation, Writing – review & editing. XL: Conceptualization, Project administration, Writing – review & editing.

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Conflict of interest

The 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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2024.1413596/full#supplementary-material

References

Aird, P. L. (2005). Heritage, natural heritage, cultural heritage and heritage tree defined. *For. Chron.* 81, 593. doi: 10.5558/tfc81593-4

Balding, M., and Williams, K. J. H. (2016). Plant blindness and the implications for plant conservation. *Conserv. Biol.* 30, 1192–1199. doi: 10.1111/cobi.12738

Bao, Q. X., Li, X., and Chen, C. W. (2009). Current situation and conservation strategy of ancient and famous tree resource in Hangzhou. *J. Zhejiang For. Sci. Technol.* 29, 77–80. doi: 10.3969/j.issn.1001-3776.2009.02.018

Bennett, A. C., McDowell, N. G., Allen, C. D., and Anderson-Teixeira, K. J. (2015). Larger trees suffer most during drought in forests worldwide. *Nat. Plants* 1, 15139. doi: 10.1038/nplants.2015.139

Blicharska, M., and Mikusinski, G. (2014). Incorporating social and cultural significance of large old trees in conservation policy. *Conserv. Biol.* 28, 1558–1567. doi: 10.1111/cobi.12341

Chao, Y., Li, J. L., and Bu, X. C. (2005). The nondestructive mensuration of living old tree's age. *Chin. Landsc. Archit.* 21, 57–61. doi: 10.3969/j.issn.1000-6664.2005.08.013

Chen, S., Li, G., Zhuo, Y., Xu, Z., Ye, Y., Thorn, J. P. R., et al. (2022). Trade-offs and synergies of ecosystem services in the Yangtze River Delta, China: response to urbanizing variation. *Urban Ecosyst.* 25, 313–328. doi: 10.1007/s11252-021-01150-2

Chen, W. Y., and Hua, J. (2017). Heterogeneity in resident perceptions of a bio-cultural heritage in Hong Kong: A latent class factor analysis. *Ecosyst. Serv.* 24, 170–179. doi: 10.1016/j.ecoser.2017.02.019

Chen, X. (2010). Diversity of ancient trees in Beijing. *Sci. Technol. Eng.* 10, 6623–6627. doi: 10.3969/j.issn.1671-1815.2010.27.004

Chi, X., Yang, G., Sun, K., Li, X., Wang, T., Zhang, A., et al. (2020). Old ginkgo trees in China:Distribution, determinants and implications for conservation. *Glob. Ecol. Conserv.* 24, e01304. doi: 10.1016/j.gecco.2020.e01304

Choat, B., Brodribb, T. J., Brodersen, C. R., Duursma, R. A., López, R., and Medlyn, B. E. (2018). Triggers of tree mortality under drought. *Nature* 558, 531–539. doi: 10.1038/s41586-018-0240-x

Colangelo, M., Camarero, J. J., Gazol, A., Piovesan, G., Borghetti, M., Baliva, M., et al. (2021). Mediterranean old-growth forests exhibit resistance to climate warming. *Sci. Total Environ.* 801, 149684. doi: 10.1016/j.scitotenv.2021.149684

Dai, B., Guo, Y., Song, X., Liu, Z., Lei, J., and Liang, H. (2020). Resource characteristics and spatial distribution pattern of ancient and rare trees in Haikou, Hainan Island. *J. Trop. Biol.* 11, 63–71. doi: 10.15886/j.cnki.rdswxb.2020.01.010

Du, R. J., Li, E. S., and Liu, G. P. (1986). *Design of Gardens and Parks.* (Beijing: Construction Industry Press of China).

Fedrigo, M., Kasel, S., Bennett, L. T., Roxburgh, S. H., and Nitschke, C. R. (2014). Carbon stocks in tem_perate forests of south-eastern Australia reflect large tree distribution and edaphic con_ditions. *For. Ecol. Manage.* 334, 129–143. doi: 10.1016/j.foreco.2014.08.025

Flora of China Editorial Committee. (2013). *Flora of China* (Beijing, China: Science Press).

Fu, L. Y. (2013). Characteristic analysis of ancient tree resources in Guangde County, Anhui Province. *Subtrop. Plant Sci.* 42, 146–152. doi: 10.3969/j.issn.1009-7791.2013.02.013

Gibbons, P., Cunningham, R. B., and Lindenmayer, D. B. (2008). What factors influence the collapse of trees retained on logged sites?: A case-control study. *For. Ecol. Manage.* 255, 62–67. doi: 10.1016/j.foreco.2007.08.020

Hanlon, V. C. T., Otto, S. P., and Aitken, S. N. (2019). Somatic mutations substan_tially increase the per-generation mutation rate in the conifer Picea sitchensis. *Evol. Lett.* 3, 348–358. doi: 10.1002/evl3.121

Hartel, T., Hanspach, J., Moga, C. I., Holban, L., Szapanyos, Á., Tamás, R., et al. (2018). Abundance of large old trees in wood-pastures of Transylvania (Romania). *Sci. Total Environ.* 613–614, 263–270. doi: 10.1016/j.scitotenv.2017.09.048

Huang, L., Jin, C., Zhen, M., Zhou, L., Qian, S., Jim, C. Y., et al. (2020). Biogeographic and anthropogenic factors shaping the distribution and species assemblage of heritage trees in China. *Urban For. Urban Green.* 50, 126652. doi: 10.1016/j.ufug.2020.126652

Huang, Y., Sun, B., Liao, S., Chen, Y., Chen, L., and Lu, Z. (2015). Resource characteristics and distribution pattern of ancient trees in Shenzhen City. *J. Plant Resour. Environ.* 24, 104–111. doi: 10.3969/j.issn.1674-7895.2015.02.15

Jim, C. Y. (2004). Spatial differentiation and landscape-ecological assessment of heritage trees in urban Guangzhou (China). *Landsc. Urban Plan.* 69, 51–68. doi: 10.1016/j.landurbplan.2003.09.008

Jim, C. Y., and Zhang, H. (2013). Species diversity and spatial differentiation of old-valuable trees in urban Hong Kong. *Urban For. Urban Green.* 12, 171–182. doi: 10.1016/j.ufug.2013.02.001

Kuchler, A. W., Mueller-Dombois, D., and Ellenberg, H. (1976). Aims and methods of vegetation ecology. *Geogr. Rev.* 66, 114. doi: 10.2307/213332

Lai, P. Y., Jim, C. Y., Tang, G. D., Hong, W. J., and Zhang, H. (2019). Spatial differentiation of heritage trees in the rapidly-urbanizing city of Shenzhen, China. *Landsc. Urban Plan.* 181, 148–156. doi: 10.1016/j.landurbplan.2018.09.017

Larjavaara, M. (2014). The world's tallest trees grow in thermally similar climates. *New Phytol.* 202, 344–349. doi: 10.1111/nph.12656

Laurance, W. F., Delamônica, P., Laurance, S. G., Vasconcelos, H. L., and Lovejoy, T. E. (2000). Rainforest fragmentation kills big trees. *Nature* 404, 836–836. doi: 10.1038/35009032

Li, K., and Zhang, G. (2021). Species diversity and distribution pattern of heritage trees in the rapidly-urbanizing province of Jiangsu, China. *Forests* 12, 1543. doi: 10.3390/f12111543

Li, Y., Fang, K., Bai, M., Cao, X., Dong, Z., Tang, W., et al. (2021). Ecological resilience of ancient Pinus massoniana trees to climate change and insect infestation in southeastern Fujian, China. *Chin. J. Appl. Ecol.* 32, 3539–3547. doi: 10.13287/j.1001-9332.202110.010

Lin, Z. D., and Tang, G. D. (2012). Investigation of ancient trees in Longgang District of Shenzhen. *Guangdong For. Sci. Technol.* 28, 63–68. doi: 10.3969/j.issn.1006-4427.2012.02.012

Lindenmayer, D. B., Blanchard, W., Blair, D., McBurney, L., and Banks, S. C. (2016). Environmental and human drivers influencing large old tree abundance in Australian wet forests. *For. Ecol. Manage.* 372, 226–235. doi: 10.1016/j.foreco.2016.04.017

Lindenmayer, D. B., and Laurance, W. F. (2017). The ecology, distribution, conservation and management of large old trees. *Biol. Rev.* 92, 1434–1458. doi: 10.1111/brv.12290

Lindenmayer, D. B., and Laurance, W. (2016). The ecology, distribution, conservation and man_agement of large old trees. *Biol. Rev.* 92, 1434–1458. doi: 10.1111/BRV.12290

Lindenmayer, D. B., Laurance, W. F., Franklin, J. F., Likens, G. E., Banks, S. C., Blanchard, W., et al. (2014). New policies for old trees: averting a global crisis in a keystone ecological structure. *Conserv. Lett.* 7, 61–69. doi: 10.1111/conl.12013

Lindenmayer, D. B., Laurance, W. F., and Franklin, J. F. (2013). Old trees: large and small–response. *Sci. (New York N.Y.)* 339 (6122), 905. doi: 10.1126/science.339.6122.905-a

Lindenmayer, D. B., Laurance, W. F., and Franklin, J. F. (2012). Global decline in large old trees. *Science.* 338, 1305–1306. doi: 10.1126/science.1231070

Liu, D., Wang, Y., Xie, C., and Xu, P. (2020). Analyses on resource characteristics and impact factors of first-class old trees in Anhui Province. *J. Plant Resour. Environ.* 29, 59–68. doi: 10.3969/j.issn.1674-7895.2020.01.08

Liu, J., Lindenmayer, D. B., Yang, W., Ren, Y., Campbell, M. J., Wu, C., et al. (2019). Diversity and density patterns of large old trees in China. *Sci. Total Environ.* 655, 255–262. doi: 10.1016/j.scitotenv.2018.11.147

Liu, Y., and Xu, C. (2013). Research progress in ancient trees health assessment. *World For. Res.* 26, 37–42. doi: 10.13348/j.cnki.sjlyyj.2013.01.015

Liu, J., Zeng, D., Tang, X., and Chen, W. (2013). Research and analyze the present situation of ancient and famous trees in SanYa city. *Trop. For.* 41, 41–44. doi: 10.3969/.j.issn.1672-0938.2013.02.011

Liu, J., Xia, S. , Zeng, D., Liu, C., Li, Y., Yang, W., et al. (2022). Age and spatial distribution of the world's oldest trees. *Conserv. Biol.* 10.1111/cobi.13907. doi: 10.1111/cobi.13907

Manning, A. D., Fischer, J., and Lindenmayer, D. B. (2006). Scattered trees are keystone structures –implications for conservation. *Biol. Conserv.* 132, 311–321. doi: 10.1016/j.biocon.2006.04.023

Manning, A. D., Fischer, J. , Felton, A., Newell, B., Steffen, W., Lindenmayer, D. B., et al. (2009). Landscape fluidity - a unifying perspective for understanding and adapting to global change. *J. Biogeogr.* 36, 193–199. doi: 10.1111/j.1365-2699.2008.02026.x

McIntyre, P. J., Thorne, J. H., Dolanc, C. R., Flint, A. L., Flint, L. E., Kelly, M., et al. (2015). Twentieth-century shifts in forest structure in California: Denser forests, smaller trees, and increased dominance of oaks. *Proc. Natl. Acad. Sci.* 112, 1458–1463. doi: 10.1073/pnas.1410186112

McPherson, E. G., Nowak, D. J., and Rowntree, R. A. (1995). *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project* (Chicago: United States Department of Agriculture).

McPherson, E. G., Simpson, J. R., Peper, P. J., Gardner, S. L., Vargas, K. E., and Xiao, Q. (2007). *Northeast community tree guide: benefits, costs, and strategic planting* (Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station). doi: 10.2737/PSW-GTR-202

Min, X., and Wang, W. (1994). Large old trees of Qufu City. *J. Jining Norm. Coll.* 3, 62–63. doi: CNKI:SUN:JNSZ

Mosseler, A., Major, J. E., and Rajora, O. P. (2002). Old-growth red spruce forests as reservoirs of genetic diversity and reproductive fitness. *Theor. Appl. Genet.* 106, 931–937. doi: 10.1007/s00122-002-1156-1

Orłowski, G., and Nowak, L. (2007). The importance of marginal habitats for the conservation of old trees in agricultural landscapes. *Landsc. Urban Plan.* 79, 77–83. doi: 10.1016/j.landurbplan.2006.03.005

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *J. Theor. Biol.* 13, 131–144. doi: 10.1016/0022-5193(66)90013-0

Shannon, C. E., and Weaver, W. (1963). *The mathematical theory of communication.* (Urbana: University of Illinois Press).

Shashua-Bar, L., Potchter, O., Bitan, A., Boltansky, D., and Yaakov, Y. (2010). Microclimate modelling of street tree species effects within the varied urban morphology in the Mediterranean city of Tel Aviv, Israel. *Int. J. Climatol.* 30, 44–57. doi: 10.1002/joc.1869

Sist, P., Mazzei, L., Blanc, L., and Rutishauser, E. (2014). Large trees as key elements of carbon storage and dynamics after selective logging in the Eastern Amazon. *For. Ecol. Manage.* 318, 103–109. doi: 10.1016/j.foreco.2014.01.005

Slik, J. W. F., Paoli, G., McGuire, K., Amaral, I., Barroso, J., Bastian, M., et al. (2013). Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. *Glob. Ecol. Biogeogr.* 22, 1261–1271. doi: 10.1111/geb.12092

Statistical Bureau of Sichuan and NBS Survey Office in Sichuan. (2022). *Sichuan Statistical Yearbook 2021.* (Beijing, China: China Statistics Press).

Statistic Bureau of Chengdu and NBS Survey Office in Chengdu. (2022). *Chengdu Statistical Yearbook 2021.* (Beijing, China: China Statistics Press).

Stephenson, N. L., Das, A. J., Condit, R., Russo, S. E., Baker, P. J., Beckman, N. G., et al. (2014). Rate of tree carbon accumulation increases continuously with tree size. *Nature* 507, 90–93. doi: 10.1038/nature12914

Sun, M. (2012). Study on the health status of typical aged trees in Shanghai City. *J. Anhui Agric. Sci.* 40, 9367–9369. doi: 10.13989/j.cnki.0517-6611.2012.17.097

Team R Core. (2014). R Foundation for Statistical Computing.

Tian, H., Pay, W., Xiang, X., and Du, H. (2014). Analysis of the characteristics of ancient trees resource in Qiannan Prefecture of Guizhou Province. *Subtrop. Plant Sci.* 43, 305–309. doi: 10.3969/j.issn.1009-7791.2014.04.009

Vandekerkhove, K., Vanhellemont, M., Vrška, T., Meyer, P., Tabaku, V., Thomaes, A., et al. (2018). Very large trees in a lowland old-growth beech (Fagus sylvatica L.) forest: Density, size, growth and spatial patterns in comparison to reference sites in Europe. *For. Ecol. Manage.* 417, 1–17. doi: 10.1016/j.foreco.2018.02.033

Venter, M., Dwyer, J., Dieleman, W., Ramachandra, A., Gillieson, D., Laurance, S., et al. (2017). Optimal climate for large trees at high elevations drives patterns of biomass in remote forests of Papua New Guinea. *Glob. Change Biol.* 23, 4873–4883. doi: 10.1111/gcb.13741

Wan, J.-Z., Li, Q.-F., Wei, G.-L., Yin, G.-J., Wei, D.-X., Song, Z.-M., et al. (2020). The effects of the human footprint and soil properties on the habitat suitability of large old trees in alpine urban and periurban areas. *Urban For. Urban Green.* 47, 126520. doi: 10.1016/j.ufug.2019.126520

Wu, M. (2019). Characteristics of annual spatial and temporal distribution of rainfall and rainfall erosivity in Chengdu. *Yangtze River* 50, 81–85. doi: 10.16232/j.cnki.1001-4179.2019.04.015

Xiang, Y., Zhou, S., Xiao, Y., Hu, T., Tu, L., and Huang, C. (2017). Effects of simulated nitrogen deposition and precipitation changes on soil organic carbon in an evergreen broad-leaved forest that is part of the Rainy Area of Western China. *Acta Ecol. Sin.* 37, 4686–4695. doi: 10.5846/stxb201604250784

Xie, C., Li, M., Jim, C. Y., and Liu, D. (2022). Environmental Factors Driving the Spatial Distribution Pattern of Venerable Trees in Sichuan Province, China. *Plants (Basel Switzerland)* 11 (24), 3581. doi: 10.3390/plants11243581

Xu, B., and Zheng, H. (2013). Identifying Age of Ancient Trees Magnolia denudate cv. Hailuo Based on the Wood Structure. *J. Northeast For. Univ.* 6, 154–156. doi: 10.3969/j.issn.1000-5382.2013.06.037

Yang, B., Qin, C., Wang, J., He, M., Melvin, T. M., Osborn, T. J., et al. (2014). A 3,500-year tree-ring record of annual precipitation on the north_eastern Tibetan Plateau. *Proc. Natl. Acad. Sci.* 111, 2903–2908. doi: 10.1073/pnas.1319238111

Yang, Y., Bao, G., Zhang, D., and Zhai, C. (2022). Spatial distribution and driving factors of old and notable trees in a fast-developing city, Northeast China. *Sustainability* 14, 7937. doi: 10.3390/su14137937

Zhang, H., Lai, P. Y., and Jim, C. Y. (2017). Species diversity and spatial pattern of old and precious trees in Macau. *Landsc. Urban Plan.* 162, 56–67. doi: 10.1016/j.landurbplan.2017.02.002

Zhang, X., Lei, Y., Pang, Y., Liu, X., and Wang, J. (2014). Tree mortality in response to climate change induced drought across Beijing, China. *Clim. Change* 124, 179–190. doi: 10.1007/s10584-014-1089-0

Zhang, Y., and Yang, J. (2020). Age estimation and spatial distribution characteristics of ancient and famous trees in Guang'an City, Sichuan Province. *J. Zhejiang AF Univ.* 37, 841–848. doi: 10.11833/j.issn.2095-0756.20190585

Zhuang, P., and Gao, X. (2002). The concept of the Rainy Zone of West China and its significance to the biodiversity conservation in China. *Biodivers. Sci.* 10, 339–344. doi: 10.3321/j.issn:1005-0094.2002.03.014