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Discussion of the Distribution Pattern and Driving Factors of Large Old Tree Resources in Beijing

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Abstract: Known as "living fossils", large old trees play an important role in ecology, landscape, and culture and are an important part of ecosystems and human settlements. The aim of this paper is to provide suggestions for the protection of urban large old tree resources and the selection of large old tree backup resources. First, we conducted a statistical analysis on the composition, distribution, and important values of large old tree species in Beijing and used Downtrend correspondence analysis (DCA) to analyze the composition of different types of habitat tree species. Second, we created a 3 km × 3 km grid within the administrative scope of Beijing, extracted the number of large old trees and tree species richness in the grid, and used geographic detectors to determine the driving factors of the spatial distribution of large old trees, as well as tree species richness differences and their interactions. A total of 40,590 large old trees in Beijing were found, belonging to 72 species, 52 genera, and 29 families. *Platycladus orientalis* (L.) Franco was the dominant tree species, with an importance value of 0.51. Among the different habitats, the large old trees were found in parks and temples, and the greatest tree species number of old trees were found in communities and the countryside; meanwhile, microgreen spaces had the lowest number of trees and tree species. The distribution of large old trees and tree species was mainly concentrated in the center of the city and the northwest. The distribution pattern of large old tree resources in Beijing is affected by the interaction of various factors. Social factors were the dominant in the distribution of large old tree resources in Beijing. The spatial distribution of large old trees was mainly affected by the scenic resort and historic site (SRHS), and the SRHS and gross domestic product (GDP) level were the most important factors influencing the richness of large old tree species. In addition, the functional value and characteristics of tree species determined the distribution of large old tree habitats. Therefore, the protection of large old tree resources requires developing scientific management and planning by managers, increasing investment in management and protection, and strengthening ecological culture publicity.

Keywords: distribution pattern; large old tree resources; driving factors; Beijing

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1. Introduction

As a bridge connecting human society and the urban ecological environment, large old trees play an important role in the stability of the urban ecosystem and the harmony of human society [1–3]. Although the definition of large old trees is ambiguous and not uniform, there is a clear definition of large old trees in China. According to China's "Administrative Measures for the Protection of Ancient and Famous Trees in Cities", large old trees refer to trees that are more than 100 years old [4,5].

According to relevant studies, forests in cities can have a variety of ecological benefits in the urban ecosystem [6]. Old trees have more crucial ecological functions than young trees [7]. For example, old trees have huge canopies, lush branches and leaves, which can lower the temperature in parts of the city and change the microclimate of the city [8], the nutrient cycle and carbon sink storage of a single tree is also far superior to those of young trees [9–11]; the reduction in urban biodiversity is mainly caused by habitat loss [12,13].

The large branches and tree holes of large old trees can provide excellent habitats for other creatures, which greatly enriches the biodiversity of cities [3,14]. Large old trees can also produce phytochemicals with many biomedical properties [11]. For example, the anti-breast cancer drug "paclitaxel" is extracted from the bark of 100-year-old mature *Taxus wallichiana* var. chinensis (Pilg.) Florin. Also, the concentration of antioxidants such as flavonoids in *Ginkgo biloba* L. is affected by the age of the tree [15,16]. For residents living in cities, large old trees record changes in local social history, affect the emotions of residents, and provide residents with places for leisure and recreation [1,17,18]. In addition, large old trees have unique values, such as landscape value, lumber value, and cultural value [17,19,20]. Therefore, abundant large old tree resources greatly improve the urban living environment and promote the stability of the urban ecosystem.

In recent years, with the development of global urbanization, the urban environment has undergone drastic changes, which inevitably bring about environmental changes. The growth of plant communities in cities is threatened, especially the number of large old tree groups, which has dropped sharply [7,21]. Larger trees (>45 cm in diameter) throughout southern Sweden have declined from historical densities of approximately 19 per hectare to 1 per hectare; in California's Yosemite National Park, the density of the largest trees declined by 24% between the 1930s and 1990s [7]. This has attracted widespread attention from scientists.

Many scientists and managers recognize that large old trees are crucial to the urban ecological environment and the quality of life of residents, they have performed assessments of large old trees health [22–24], pest and disease control [25,26], There have been many studies on the distribution of large old tree resources [4,19,27–31]. Previous studies have shown that the spatial distribution of large old tree resources may be affected by natural factors such as climate [4,28,30,32], natural disasters [33], slope and altitude [29,34], as well as human factors such as population density [30,35], habitat fragmentation and land use types [12,36]. In recent years, there have been an increasing number of studies on the protection of large old trees. For example, the acceptance of the ancient tree landscape by residents was explored in Poland [20], a study was conducted to determine whether Guangdong residents were willing to pay money to protect the large old trees in the city [37], environmental and human drivers influencing large old tree abundance in Australian wet forests [29], and large old trees with special cultural implications in southwest China that are worshipped by residents and protected were also studied [35]. In addition, some regions have emphasized the importance of specific policies and legislation; for example, in England, Sydney (Australia), Bangkok (Thailand), Auckland and China, policies have been formulated with the hope of improving the protection of large old trees; However, policies implemented at a single level are insufficient for the protection of large old trees or urban forests [38]. In a human-led social environment, the acceptance of urban residents, social history, and social culture play positive or negative roles in the protection of large old tree resources [39,40]. In addition, the positive correlation between the income of the societal-family economy and the diversity of urban forest trees is called the "luxury effect", which has also been shown to affect the diversity of large old tree resources [37,41]. Therefore, the spatial heterogeneity of urban large old tree resources is the comprehensive result of urban environmental filtering and human selection, indicating that the driving factors of large old tree spatial differences often interact. However, the relationship between the interaction among influencing factors and the spatial heterogeneity of urban large old tree resources has not been explored sufficiently. In particular, the driving factors of the spatial distribution of large old trees in a complex urban environment requires further study.

Previous research has mainly focused on the division of urban administrative areas or research on the city as a unit [4,18,19,30]; however, based on the traditional ecological species-area hypothesis, a larger area can support more tree species and other species [42], and the area of administrative regions or cities is quite different, resulting in deviation. Therefore, we divided the study area into regions of equal areas using the Create Fishnet tool in ArcGIS and counted the number and species of large old trees in each grid to eliminate the bias introduced by the species-area hypothesis. Some of the commonly used statistical methods, such as linear regression, generalized linear regression, Pearson's correlation, and redundancy analysis, are not very convenient for exploring the interaction of different factors. The geographical detector addresses this problem very well.

Against the backdrop of the current global urbanization trend threatening the security of the urban ecological environment, research on the distribution of large old tree resources is important for the protection and inheritance of urban ecological culture and the enrichment of urban forest species diversity. Therefore, in this study, we focused on the large city of Beijing and analyzed the basic distribution pattern, influencing factors and differences in the distribution of large old tree species in different habitats based on field investigation and data obtained from the Beijing large old trees information database. We assessed the following: (1) the spatial distribution pattern and species composition of large old trees in Beijing, (2) the main factors influencing the spatial distribution and species abundance of large old trees in large cities and their interactions, and (3) large old trees in different types of habitats and the reasons for the differences in the distribution of tree species. Overall, our goal was to identify the leading factors of the differences in the spatial distribution of large old tree resources and explore the reasons for the differences in the distribution of large old tree habitats of different tree species in cities with severe urbanization to provide a reference for the protection of large old trees in cities and the selection of urban large old tree reserve resources. We also aimed to provide a scientific basis for the construction of urban forests and the improvement of human settlements and provide residents with acceptable and sustainable suggestions to help urban managers make decisions that are beneficial to urban ecological protection.

2. Materials and Methods

2.1. Overview of the Study Area

Beijing is between 115.7° and 117.4° east longitude and 39.4° and 41.6° north latitude, with a total area of 16,410 km^2, 62% of which is mountains and 38% of which is plains. It has a warm temperate semihumid and semiarid monsoon climate, with an annual average temperature of 8 to 12 °C and an annual precipitation of 400 to 600 mm. Various soil types occur in Beijing. Cinnamon soil, which is mostly neutral to slightly alkaline, dominates the zonal soil. The diverse natural environment nurtures rich species resources, among which *Platycladus orientalis* (L.) Franco and *Styphnolobium japonicum* (L.) Schott were selected as city trees.

Beijing has a 3000-years history. It has been the capital of China for more than 850 years. The rich social and historical background has laid a foundation for rich large old tree resources. Before the founding of the People's Republic of China, Beijing's urbanization was mainly concentrated in the Second Ring Road. With the development of the society and economy, especially after the reform and opening-up in 1978, cities continued to expand, and the population continued to increase [43]. As of 2021, Beijing had a GDP of 402.696 billion yuan and a permanent population of 21.886 million. Compared to cities in China and around the world, it is a megacity.

2.2. Data Source and Preprocessing

A 3 km × 3 km grid was created within the administrative scope of Beijing. The number of large old trees and tree species richness in the grid was measured and used as dependent variables. Three types of explanatory variables were included in the model. Population density (PD), distance from the city center (DFC), and building density (BD) were included as urbanization factors; scenic resort and historic site (SRHS), and gross domestic product (GDP) were included as social factors; and the annual mean temperature (AMT) (1970–2000), the annual mean rainfall (ANP), and elevation (EL) were included as natural factors. Thus, a total of 8 explanatory variables were used; the center of the divided 2005 grids was used as the sampling point, and the inverse distance weight was used to extract the spatial attributes of the independent variable data and perform hierarchical processing (Figure 1).

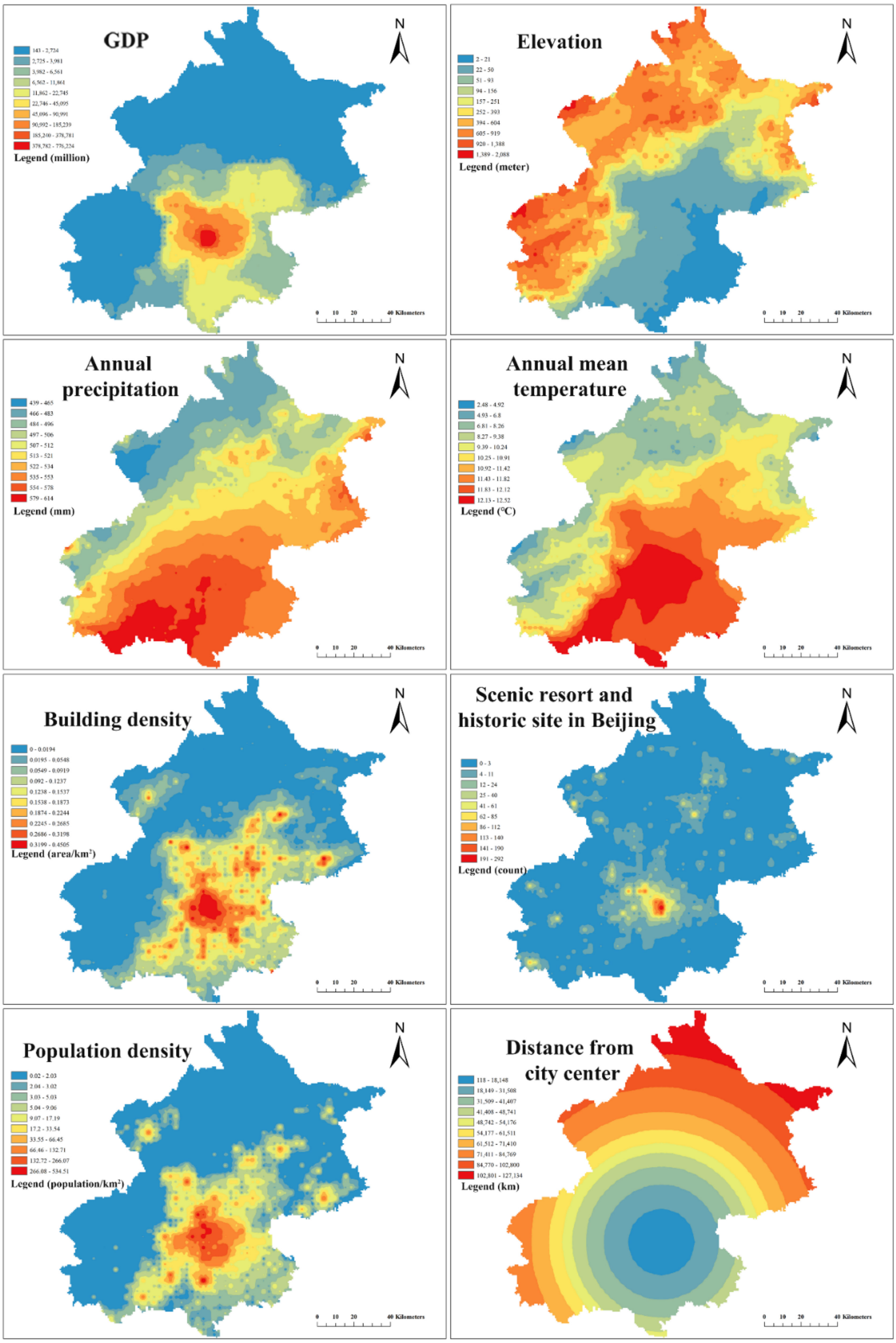


Figure 1. Eight explanatory variables.

The large old tree resource data in Beijing were obtained from the large old tree database and field survey of the Beijing Municipal Bureau of Landscaping in 2021. The SRHS comes from Amap (https://www.amap.com/) (accessed on 8 May 2022) through the application API, and Python was used to programmatically collect the coordinate points of scenic spots and count the number located in the grid. The elevation data were obtained from the 12.5 m elevation data of the Geospatial Data Cloud Platform of the Chinese Academy of Sciences (http://www.gscloud.cn/) (accessed on 14 May 2022). The building density data came from the National Qinghai-Tibet Plateau Science Data Center (http://data.tpdc.ac.cn/) (accessed on 16 May 2022), referring to the Beijing building area data [44], and ArcGIS was used to calculate the building density of each grid. The population density was derived from the 2020 format in WorldPop (https://www.worldpop.org/) (accessed on 15 May 2022) as 1 km × 1 km population density data. Rainfall and temperature data were obtained from WorldClim (https://worldclim.org/) (accessed on 15 May 2022) in the format of 1 km × 1 km of average annual rainfall and average annual temperature from 1970 to 2000; Beijing GDP vector data were sourced from the 2015 China GDP spatial distribution km dataset provided by the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/) (accessed on 16 May 2022) [45].

2.3. Research Methods

In downtrend correspondence analysis (DCA), species are arranged in a certain space so that similar species are close and dissimilar species are farther away. The ordering can reveal the ecological relationship between species and the environment. Therefore, DCA was used to sort large old tree species' habitats to eliminate the "bow effect" and to analyze the relationship between species and habitat [46].

Inverse distance weight (IDW) involves predicting data based on the principle that things that are closer to each other are more similar than things that are farther away [47]. In the IDW method, the measurement values around the predicted position are compared with the measurement values farther away from the predicted position. The measurement value closest to the predicted position has a greater impact on the predicted value, and its calculation formula is as follows:

$$A = \left[\frac{\sum_{i=1}^{n} A_i}{d_i^2}\right] / \left[\sum_{i=1}^{n} \frac{1}{d_i^2}\right] \tag{1}$$

where A is the value of the predicted point, A_i is the measured value of point i, d_i is the distance from the estimated point to the measured point i, and n is the number of measured points involved in the interpolation.

A geographical detector (GeoD) is a spatial distribution model based on spatial heterogeneity that mainly includes factor detection, interaction detection, risk area detection and ecological detection [48]. In this study, we selected factor detection and interaction detection to explore the differences in the spatial distribution of large old tree resources in Beijing. Factor detection was primarily used for assessing the explanatory power of the independent variable in determining the value of the dependent variable, which is represented by the q value. The value ranges between 0 and 1. The larger the value is, the stronger the explanatory power.

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{2}$$

In the formula, $h = 1, \ldots, L$ is the number of categories of the independent variable X; N_h and N are the number of units in category h and the entire region, respectively; and σ_h^2 and σ^2 are the variances of category h and dependent variable Y in the region, respectively. SSW and SST are the sums of the variances for all categories of the independent variable X and the total variance within the region, respectively.

Interaction can explore whether the explanatory power of different independent variables is enhanced, weakened or independent, and whether a linear effect can be detected (see Table 1). Research on the interaction of factors is of great significance.

Table 1. Interaction between A and B.

Comparison	Interaction Contribution
$P(A \cap B) > P(A)$ or $P(B)$	Enhance
$P(A \cap B) > P(A)$ and $P(B)$	Enhance, bivariate
$P(A \cap B) > P(A) + P(B)$	Enhance, nonlinear
$P(A \cap B) < P(A) + P(B)$	Weaken
If $P(A \cap B) < P(A)$ or $P(B)$	Weaken, univariate
$P(A \cap B) < P(A)$ and $P(B)$	Weaken, nonlinear
$P(A \cap B) = P(A) + P(B)$	Independent

2.4. Indicators and Calculations

The accurate classification of habitats where large old trees grow is helpful for the study of large old tree resources. Combined with the distribution characteristics and research content of large old trees in Beijing, the growth habitats of large old trees were divided into 7 categories: parks, mausoleums, microgreen spaces, temples, communities, roads, and suburbs. The specific divisions and definitions are shown in Table 2.

Table 2. Classifications and ranges of large old tree habitats in Beijing.

Code	Habitat Type	Scope
GY	Park	All royal gardens in Beijing and public gardens for public recreation and rest.
LM	Cemetery	Tombs containing emperors and other deceased people.
LD	Microgreen space	Small-scale green areas beside streets and buildings.
SM	Temple	All religious sites, such as Buddhist and Taoist temples.
SQ	Community	Residential areas, office areas, schools and other areas of work and life.
DL	Roadside	Only road areas beside main and secondary roads.
XC	Countryside	Areas with less human activity, such as areas outside cities and wilderness areas.

Based on the large old tree grade standard in the Regulations on the Protection and Management of Large old and Famous Trees in Beijing, trees were divided into two grades: grade 1 ($\geq$300 years) and grade 2 ($\geq$100 years).

Based on the optimal q value of the data, the optimal classification number and classification threshold of each variable were determined. The building density was divided into 7 grades, the population density was divided into 8 grades, the elevation was divided into 7 grades, the annual average rainfall was divided into 8 grades, the annual average temperature was divided into 8 grades, the number of scenic spots was divided into 5 grades, and the city center was divided into 5 grades. The distance was divided into 3 levels.

The relative importance of different species is expressed as a composite value denoted by the importance value (IV) [18].

$$IV = (RA + RD) \times 100/2 \quad (3)$$

where RA = number of trees in a species/total number of trees in the study area and RD = basal area at breast height of a species/total basal area in the study area.

Tree species richness is determined by the number of tree species represented in a statistical unit.

2.5. Data Processing

Relevant statistics, data preprocessing, Create Fishnet and inverse distance weight interpolation analysis in data processing were performed in Excel 2019 and ArcGIS 10.2.

The DCA analysis was performed using Conoco 5. The GD package in R language was used for the grading of independent variables and the driving factor detection of the spatial distribution of large old trees was completed using Geo Detector software. The images were generated in Origin 2021.

3. Results

3.1. Distribution of Large Old Tree Resources

Beijing was rich in large old tree species resources (Table 3), with 72 species belonging to 52 genera and 29 families and 40,590 large old trees. Among them were 8 evergreen species, accounting for 88%, and 64 deciduous species, accounting for 12%. First-class large old trees accounted for 15%, and second-class large old trees accounted for 85%. Figure 2a shows that the importance value of *P. orientalis* was 0.5103, and *P. orientalis* was the dominant large old tree species in Beijing. In addition to *P. orientalis*, which had an importance value greater than 0.1, the other dominant species were *Pinus tabuliformis* Carr., *Sabina chinensis* (L.) Ant., and *S. japonicum*. The total importance value of the first four species was 0.926.

Table 3. Statistical table of large old tree resources in Beijing.

Type	Evergreen	Fallen Leaves	Level 1	Level 2	Total
Family	2	27	21	26	29
Genus	6	46	30	48	52
Species	8	64	36	64	72
Tree count (trees)	35,709	4881	6150	34,440	40,590

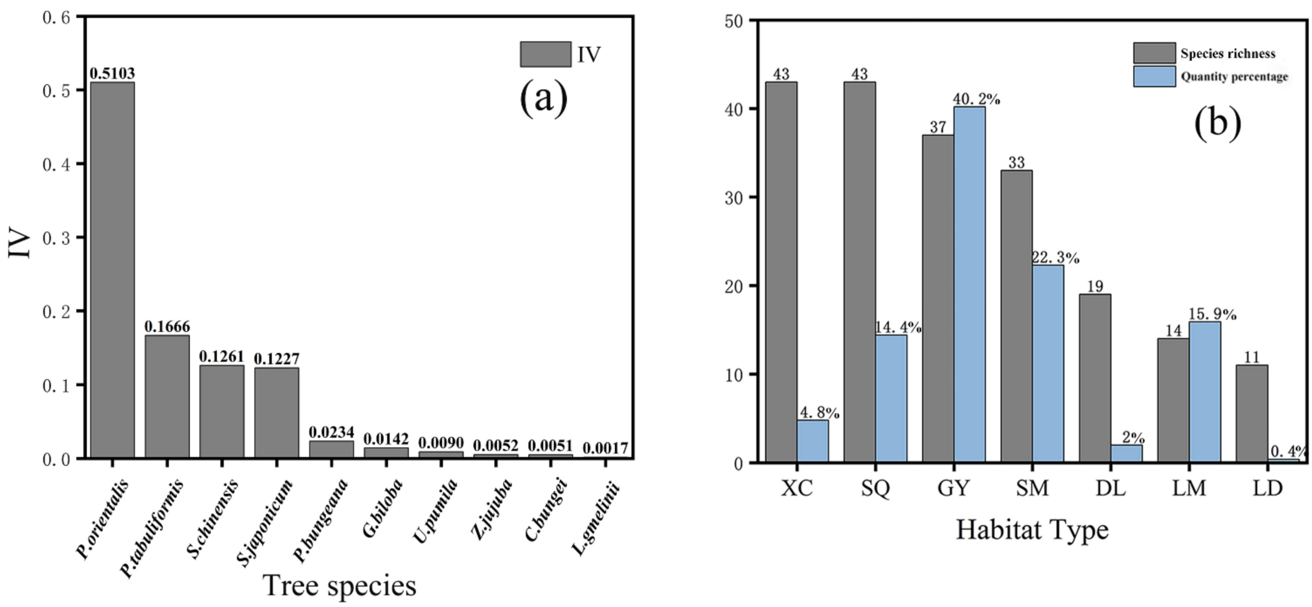
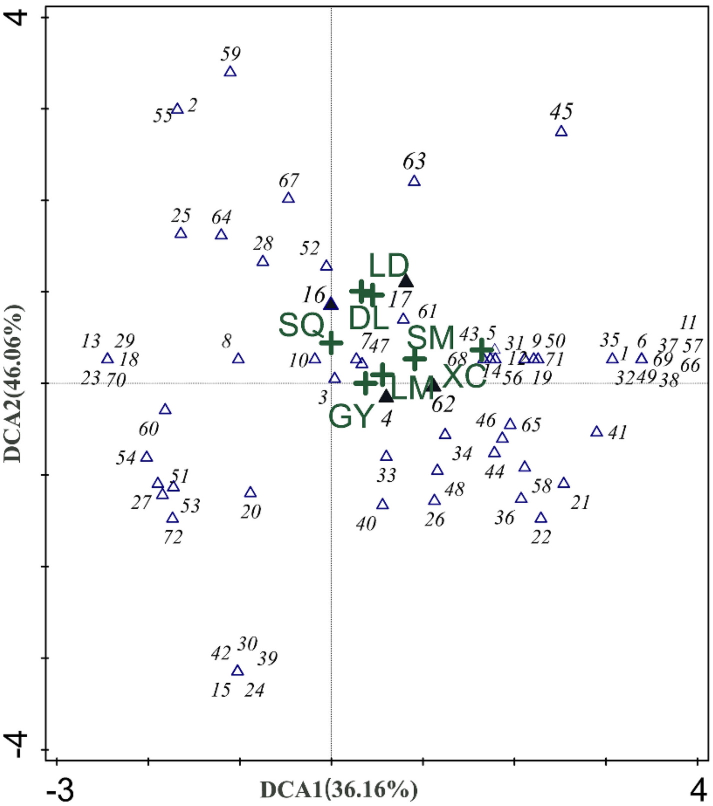


Figure 2. Statistical map of the distribution of the top ten tree species (**a**) and habitats with importance values of large old trees in Beijing (**b**) Remarks: (GY: park, LM: cemetery, SQ: community, SM: temple, DL: roadside, LD: microgreen space, and XC: countryside).

3.2. Habitat Distribution

According to the habitat classification and statistics of different habitats (Figure 2b), the order of the number of large old trees in different habitats was as follows: park (40.2%) > temple (22.3%) > cemetery (15.9%) > community (14.4%) > countryside (4.8%) > roadside (2.0%) > microgreen spaces (0.4%). The tree species distribution in descending order was as follows: community = countryside > park > temple > roadside > cemetery > microgreen spaces.

The results showed (Figure 3) that DCA explained 82.22% of the total variance (36.16% for axis 1 and 46.06% for axis 2). Overall, species in different habitats were quite different. Except for the cemetery, roadsides, and microgreen spaces, which had no unique tree species, the others had their own endemic tree species. The tree species in each habitat included seven species: *Pinus bungeana* Zucc., *P. orientalis*, *S. chinensis*, *S. japonicum*, *G. biloba*, *P. tabuliformis*, and *Catalpa bungei* C. A. Mey. The park was close to the center and has five endemic species, such as Radix Aucklandiae and *Chimonanthus praecox* (L.) Link. The cemetery is dominated by *P. orientalis* and *P. tabuliformis*, and no endemic species were found. In temples, the species *G. biloba*, *P. orientalis* and *P. tabuliformis* were the closest and included two endemic species, *Yulania* × *soulangeana* (Soul.-Bod.) D. L. Fu and *Broussonetia papyrifera* (L.) Vent. *S. chinensis* was the main species in the microgreen spaces. The community species were rich (mainly *S. japonicum*, *Catalpa ovata*, *Morus alba*, and *Ziziphus jujuba*) and include five endemic tree species (*Ziziphus jujuba* Mill., *Catalpa ovata* G. Don, and *Morus alba L.*). The roadsides were dominated by *S. japonicum*, and other species included *Ulmus pumila* L. and *P. orientalis*. The countryside mainly included *Toxicodendron vernicifluum* (Stokes) F. A. Barkl., *Quercus aliena* Bl. and *Quercus mongolica* Fisch. ex Ledeb., as well as 11 endemic species, such as *Quercus mongolica* Fisch. ex Ledeb. and *Swida walteri* (Wanger.) Sojak.



Serial number	Tree species	Serial number	Tree species
1	*Syringa oblata var. alba*	38	*Swida walteri*
2	*Fraxinus chinensis*	38	*Populus tomentosa*
3	*Pinus bungeana*	39	*Carya illinoinensis*
4	*Platycladus orientalis*	40	*Tilia mongolica*
5	*Ailanthus altissima*	41	*Quercus mongolica*
6	*Salix babylonica*	42	*Rosa banksiae*
7	*Robinia pseudoacacia*	43	*Tilia platyphylla*
8	*Syringa oblata*	44	*Aesculus chinensis*
9	*Pyrus betulifolia*	45	*Toxicodendron*
10	*Eucommia ulmoides*	46	*Pteroceltis tatarinowii*
11	*Tilia tuan*	47	*Catalpa bungei*
12	*Yulania soulangeana*	48	*Morus alba*
13	*Pterocarya stenoptera.*	49	*Populus davidiana*
14	*Broussonetia papyrifera*	50	*Quercus variabilis*
15	*Hovenia acerba*	51	*Metasequoia glyptostroboides*
16	*Sabina chinensis*	52	*Euonymus maackii*
17	*Styphnolobium japonicum*	53	*Ziziphus jujuba var. spinosa*
18	*Malus spectabilis*	54	*Euonymus alatus*
19	*Juglans regia*	55	*Xanthoceras sorbifolium*
20	*Diospyros lotus*	56	*Firmiana simplex*
21	*Quercus aliena*	57	*Populus pseudomaximowiczii*
22	*Quercus dentata*	58	*Acer pictum*
23	*Styphnolobium japonicum*	59	*Celtis bungeana*
24	*Phellodendron amurense.*	60	*Cedrus deodara*
25	*Catalpa speciosa*	61	*Ginkgo biloba*
26	*Pistacia chinensis*	62	*Pinus tabuliformis*
27	*Populus canadensis*	63	*Ulmus pumila*
28	*Melia azedarach*	64	*Yulania denudata*
29	*Picrasma quassioides*	65	*Acer truncatum*
30	*Chimonanthus praecox*	66	*Picea asperata*
31	*Chionanthus retusus*	67	*Ziziphus jujuba*
32	*Sabina chinensis*	68	*Gleditsia sinensis*
33	*Styphnolobium japonicum '*	69	*Maclura tricuspidata*
34	*Koelreuteria paniculata*	70	*Catalpa ovata*
35	*Larix gmelinii*	71	*syringa pekinensis*
36	*Quercus acutissima*	72	*Wisteria sinensis*

Figure 3. Species-habitat DCA results (Note: Cross marks represent different habitats (refer to Table 2); see the table to the right for tree species).

3.3. Spatial Distribution and Driving Factor Analysis of Large Old Tree Resources

3.3.1. Spatial Distribution of Large Old Trees and Tree Species Distribution

The statistical results showed (Figure 4) that the distribution pattern of the number of large old trees and tree species richness in Beijing was mainly concentrated in the center of the city and the mountainous areas in the northwest, while the number of large old trees in the plains in the southeast was lower.

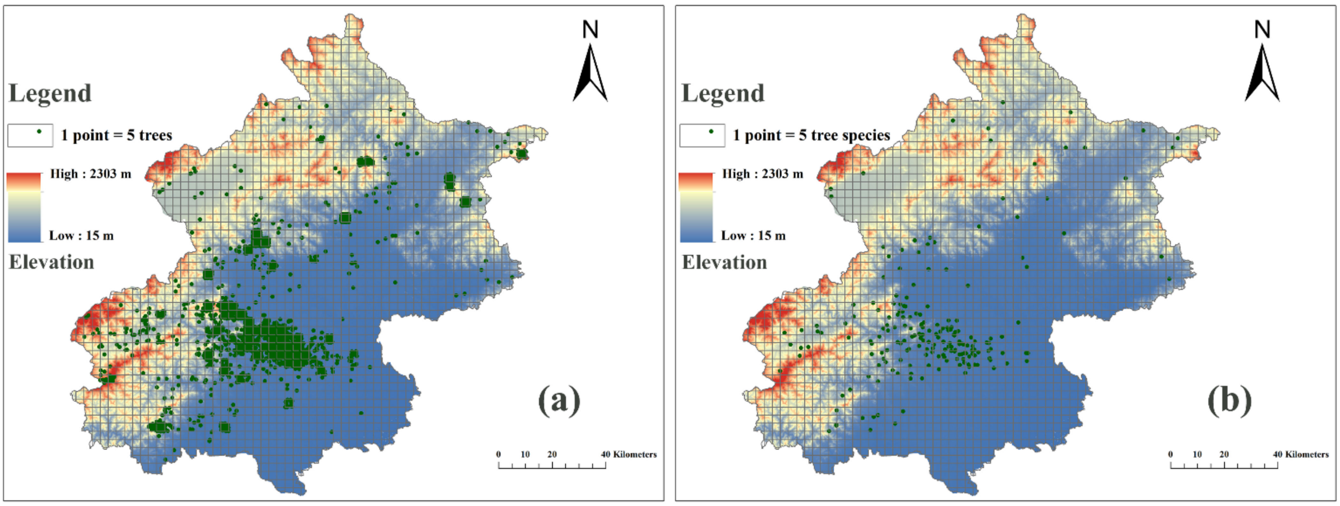


Figure 4. Spatial distribution (**a**) and tree species distribution (**b**) of large old trees in Beijing.

3.3.2. Analysis of Driving Factors of Large Old Tree Distribution

The results of the GeoD (Table 4) showed that in the spatial distribution of large old trees, except for the ANP ($p > 0.05$), the other seven variables were significantly related to the spatial distribution of large old trees ($p < 0.01$). The q value in descending order was as follows: SRHS > DFC > GDP > BD > PD > AMT > EL. The eight explanatory variables were significant for the richness of large old tree species ($p < 0.01$). The order of the q values was as follows: SRHS > GDP > DFC > PD > BD > AMT > EL > ANP. SRHS, GDP and DFC were closely related to the richness of large old tree species in Beijing.

Table 4. Factor detection results.

Explanatory Variables	Spatial Distribution of Large Old Trees		Species Richness	
	q Statistic	p Value	q Statistic	p Value
BUD	0.0329	0.000	0.2148	0.000
GDP	0.0975	0.000	0.3662	0.000
PD	0.0297	0.000	0.2257	0.000
DFC	0.1337	0.000	0.2330	0.000
ANP	0.0070	0.052	0.0403	0.000
AMT	0.0272	0.000	0.1612	0.000
SRHS	0.3706	0.000	0.3681	0.000
EL	0.0146	0.000	0.0971	0.000

The interactive detection of GeoD (Figure 5, Table 5) showed that the interaction between various factors exhibited nonlinear enhancement and dual-factor enhancement for the spatial distribution and tree species richness of large old trees. In particular, the explanatory power (q value) of the interaction between the SRHS and PD for the spatial distribution of the number of large old trees was 0.84, while the interaction between the SRHS and GDP had an explanatory power of 0.523 for tree species richness. The distribution pattern of large old tree resources in Beijing was affected by a variety of factors, but it was mainly related to social and human activities.

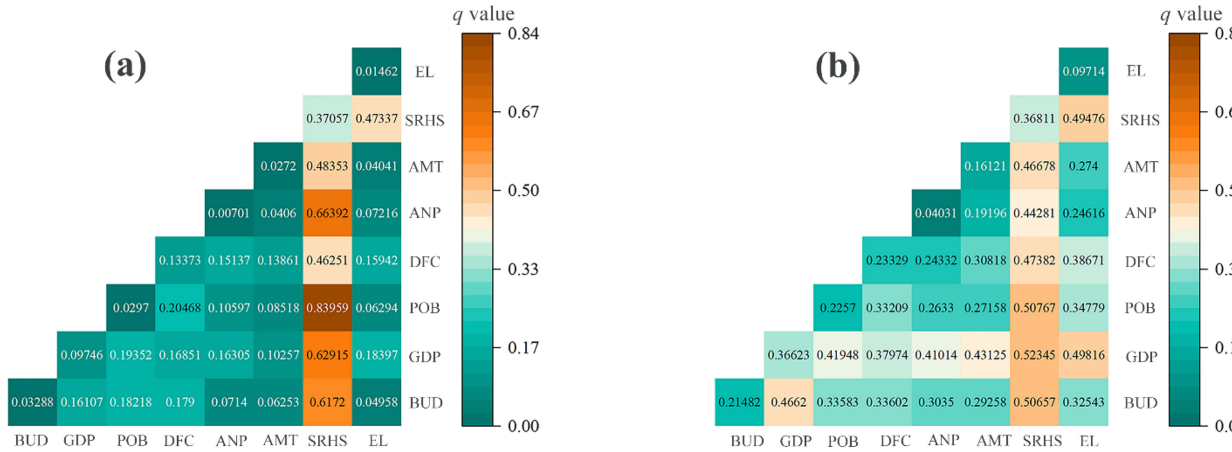


Figure 5. The influence of the interaction between the explanatory variables on the spatial distribution of large old trees (**a**) and the distribution of tree species (**b**).

Table 5. Interaction effects of explanatory variables.

	Spatial Distribution of Large Old Trees			Species Richness		
Variable	***q***	**A + B**	**Interaction Contribution**	***q***	**A + B**	**Interaction Contribution**
BUD ∩ GDP	0.1611	0.0329 + 0.0975 = 0.1303	Enhance, nonlinear	0.4662	0.2148 + 0.3662 = 0.5810	Enhance, bivariate
BUD ∩ POB	0.1822	0.0329 + 0.0297 = 0.0626	Enhance, nonlinear	0.3358	0.2148 + 0.2257 = 0.4405	Enhance, bivariate
BUD ∩ DFC	0.1790	0.0329 + 0.1337 = 0.1666	Enhance, nonlinear	0.3360	0.2148 + 0.2330 = 0.4481	Enhance, bivariate
BUD ∩ ANP	0.0714	0.0329 + 0.0070 = 0.0399	Enhance, nonlinear	0.3035	0.2148 + 0.0403 = 0.2551	Enhance, nonlinear
BUD ∩ AMT	0.0625	0.0329 + 0.0272 = 0.0601	Enhance, nonlinear	0.2926	0.2148 + 0.1612 = 0.3760	Enhance, bivariate
BUD ∩ SRHS	0.6172	0.0329 + 0.3706 = 0.4035	Enhance, nonlinear	0.5066	0.2148 + 0.3681 = 0.5829	Enhance, bivariate
BUD ∩ EL	0.0496	0.0329 + 0.0146 = 0.0475	Enhance, nonlinear	0.3254	0.2148 + 0.0971 = 0.3119	Enhance, nonlinear
GDP ∩ POB	0.1935	0.0975 + 0.0297 = 0.1272	Enhance, nonlinear	0.4195	0.3662 + 0.2257 = 0.5919	Enhance, bivariate
GDP ∩ DFC	0.1685	0.0975 + 0.1337 = 0.2312	Enhance, bivariate	0.3797	0.3662 + 0.2333 = 0.5995	Enhance, bivariate
GDP ∩ ANP	0.1630	0.0975 + 0.0070 = 0.1045	Enhance, nonlinear	0.4101	0.3662 + 0.0403 = 0.4065	Enhance, nonlinear
GDP ∩ AMT	0.1026	0.0975 + 0.0272 = 0.1247	Enhance, bivariate	0.4313	0.3662 + 0.1612 = 0.5274	Enhance, bivariate
GDP ∩ SRHS	0.6292	0.0975 + 0.3706 = 0.4681	Enhance, nonlinear	0.5234	0.3662 + 0.3681 = 0.7343	Enhance, bivariate
GDP ∩ EL	0.1840	0.0975 + 0.0146 = 0.1121	Enhance, nonlinear	0.4981	0.3662 + 0.0971 = 0.4633	Enhance, nonlinear
POB ∩ DFC	0.2047	0.0297 + 0.1337 = 0.1634	Enhance, nonlinear	0.3321	0.2257 + 0.2333 = 0.4590	Enhance, bivariate
POB ∩ ANP	0.1060	0.0297 + 0.0070 = 0.0367	Enhance, nonlinear	0.2633	0.2257 + 0.0403 = 0.2660	Enhance, bivariate
POB ∩ AMT	0.0852	0.0297 + 0.0272 = 0.0569	Enhance, nonlinear	0.2716	0.2257 + 0.1612 = 0.3869	Enhance, bivariate
POB ∩ SRHS	0.8396	0.0297 + 0.3706 = 0.4003	Enhance, nonlinear	0.5077	0.2257 + 0.3681 = 0.5938	Enhance, bivariate
POB ∩ EL	0.0629	0.0297 + 0.0146 = 0.0443	Enhance, nonlinear	0.3478	0.2257 + 0.0971 = 0.3228	Enhance, nonlinear
DFC ∩ ANP	0.1514	0.1337 + 0.0070 = 0.1407	Enhance, nonlinear	0.2433	0.2333 + 0.0403 = 0.2736	Enhance, bivariate
DFC ∩ AMT	0.1386	0.1337 + 0.0272 = 0.1609	Enhance, bivariate	0.3082	0.2333 + 0.1612 = 0.3945	Enhance, bivariate
DFC ∩ SRHS	0.4625	0.1337 + 0.3706 = 0.5043	Enhance, bivariate	0.4738	0.2333 + 0.3681 = 0.6014	Enhance, bivariate
DFC ∩ EL	0.1594	0.1337 + 0.0146 = 0.1483	Enhance, nonlinear	0.3867	0.2333 + 0.0971 = 0.3304	Enhance, nonlinear
ANP ∩ AMT	0.0406	0.0070 + 0.0272 = 0.0342	Enhance, nonlinear	0.1920	0.0403 + 0.1612 = 0.2015	Enhance, bivariate
ANP ∩ SRHS	0.6639	0.0070 + 0.3706 = 0.3776	Enhance, nonlinear	0.4428	0.0403 + 0.3681 = 0.4084	Enhance, nonlinear
ANP ∩ EL	0.0722	0.0070 + 0.0146 = 0.0216	Enhance, nonlinear	0.2462	0.0403 + 0.0971 = 0.1374	Enhance, nonlinear
AMT ∩ SRHS	0.4835	0.0272 + 0.3706 = 0.3978	Enhance, nonlinear	0.4668	0.1612 + 0.3681 = 0.5293	Enhance, bivariate
AMT ∩ EL	0.0404	0.0272 + 0.0146 = 0.0418	Enhance, bivariate	0.2740	0.1612 + 0.0971 = 0.2583	Enhance, nonlinear
SRHS ∩ EL	0.4734	0.3706 + 0.0146 = 0.3852	Enhance, nonlinear	0.4948	0.3681 + 0.0971 = 0.4652	Enhance, nonlinear

4. Discussion

4.1. Driving Factors of Spatial Heterogeneity and Species Richness of Large Old Trees in Beijing

The GeoD model showed that social factors (SRHS and GDP) were the dominant factors in the spatial distribution and species distribution of large old trees in Beijing. Most previous studies focused on the impact of urbanization on large old tree resources, while the impact of social factors on large old tree resources and even urban biodiversity was overlooked [49]. Complex social factors, including personal needs, cultural traditions, economic level, and accepted knowledge of ecological protection, affect the composition and distribution of urban forests in human settlements [21,50]. The preference, culture, and ecological experience of social residents determine the conservation value of large old trees [39], and the significant difference in the impact of different ethnic groups on large old tree resources verified this hypothesis [35]. Therefore, the results of this study showed that in heavily urbanized cities, the impact of social factors on large old tree resources exceeded that of urbanization and natural factors. This finding was a key breakthrough indicating that social factors can be an effective way to protect urban large old trees.

Most previous studies qualitatively described the importance of history and culture to the distribution of large old tree resources. Our study quantitatively verified this point of view for the first time. The spatial distribution of large old trees in Beijing was mainly affected by the SRHS. According to the website of the Beijing Municipal Bureau of Cultural Relics (Beijing.gov.cn), Beijing has six world cultural heritage sites and more than 120 national key protection units, mainly royal relics and temples, that dominate the pattern of scenic spots in Beijing [51]. Although people did not intend to build an ecologically civilized city in the past, thanks to the protection of social, historical, and cultural relics by managers, many large old trees have been preserved, and the development of royal gardens and temple gardens in scenic spots has also greatly enriched the species richness of large old trees. This demonstrates that the protection of urban historical relics and culture is helpful for social and cultural history and also greatly promotes the stability of urban ecosystems.

In addition, studies have found that socioeconomic status (GDP level) has an important impact on the abundance of large old tree species; the results of other studies have shown that this is a common phenomenon [30,37]; Socioeconomic factors (GDP) showed a stronger correlation in Beijing. In addition to Beijing retaining many historical relics, studies have shown that the level of residents' economic income determines their willingness to pay for the protection of large old trees [37]. In addition, the management of large old trees in Beijing is under the unified management of the landscaping department, and the management expenses of the management department are guaranteed to be the economic basis for the healthy management and protection of large old trees [52]. Many studies have shown that the increase in management costs and the enhancement of social residents' awareness of protection has a positive effect on the abundance of large old tree resources and urban plants.

Urbanization factors (PD, BD, and DFC) also have a certain explanatory power for the spatial distribution of large old tree resources and the abundance of large old tree species, but this does not mean that the urbanization process will promote the protection of large old tree resources because the urbanization process will inevitably destroy the habitat of urban plant communities [43]. Geographically, this is mainly because areas with relatively high levels of urbanization are consistent with the range of large old residential areas in Beijing [53,54], and the worship of large old trees by social residents enables the preservation of local large old tree resources [18,35]. In contrast to the findings of other studies [4,30,34], the relationship between natural factors (EL, AMT, and ANP) and the spatial distribution pattern of large old trees in Beijing was relatively low among the explanatory variables, and the ANP was not significant ($p < 0.05$). This was mainly because in cities with a relatively long history, the impact of human factors on large old trees is more serious, and human selection reduces the impact of natural factors; in addition, there is less climate change at the urban scale [55]. Therefore, the study of the spatial distribution pattern of urban large-scale old trees should focus on the influence of human factors rather than that of natural factors.

We also explored the interactive effects of different factors on the spatial distribution of large old trees and the distribution of tree species. The results showed that the interaction between the factors had nonlinear enhancement and double-factor enhancement for the interpretation of the spatial distribution of large old trees and the species richness of large old trees. This was consistent with the finding of other scholars [2,19,30]. Urban large old tree resources are affected by the comprehensive effect of many factors, and the distribution of large old tree resources in different urban areas is quite different [4]. This difference cannot be fully explained by a single factor. For example, the explanatory power of a single factor of population density on the spatial distribution of large old trees in Beijing was not high, but the explanatory power of the interaction with the number of scenic spots was the highest. This suggests that a single factor with a larger influence may mask the influence of other single factors. On the other hand, many factors affected large old trees in the city. In this study, we only assessed the driving factors of the spatial distribution of large old trees and tree species richness in Beijing from a small number of directions. To understand the reasons for the differences in the distribution of large old tree resources in more detail, further research from multiple aspects is needed.

4.2. The Functional Value of Tree Species Determines the Habitat of Large Old Trees

The statistical analysis and DCA results show that the composition of tree species in different habitats in Beijing is quite different. The countryside mostly contained some ecologically protected tree species, which only appeared in the countryside; roadside and microgreen spaces mainly had shading landscape tree species; temples contained tree species with religious and cultural implications; evergreen trees such as pine and cypress were found in cemeteries; parks mainly had some cultural and ornamental tree species; community tree distribution was more complex, and mainly for shading, economic, ornamental greening and cultural purposes [41,56]. This was similar to the distribution of large old tree habitats in Jiangsu Province and Macau [4,57], indicating that different tree species will be chosen in different types of habitats according to different value requirements, and the functional value and characteristics of tree species determine the habitat of large old trees.

Trees on the roadside mainly provided the functions of landscape and shading. Due to the ecological consequences of the high emission of toxic elements by traffic into the environment [58], the plants growing near the road extract the elements into the above-ground plant organs, resulting in difficulties in the formation of large old tree resources. Near temples, temple gardens have been formed with unique cultures and styles [59]. Plants with graceful posture, rich cultural meaning and longevity, such as *P. orientalis*, *G. biloba*, and *Y. denudata*, were often used in northern temples to show the continuity of Buddhism and its long history [59,60]. This promotes the species richness of large old trees. The solemn atmosphere in the cemetery limits the choice of tree species. As the preferred tree species in cemeteries, pine and cypress have been planted in cemeteries around the world [61]. In China, emperors pursued the beautiful vision of everlasting greenness; thus, pine and cypress were mostly used as green trees in royal parks and cemeteries, which also influenced the distribution of large old trees in cemeteries. Parks have recreational attributes and a wide habitat. Abundant tree species are planted in parks to maintain their recreational and leisure functions [18,57]. Therefore, most of the large old trees in the park were landscape tree species. Because the countryside is located outside the city, it is less affected by urbanization, avoids the interference of human selection on tree growth, and retained a considerable number of large old tree species [27,34]. On the other hand, human selection also promotes the abundance of tree species. Residents have planted tree species with different functions according to their own preferences or needs [62,63]. These trees have benefited from human protection during urban changes and have formed a richer collection of large old trees. The tree species distribution pattern provides information for understanding the urban distribution of large old trees and provides guidance for the construction of green and harmonious human settlements.

4.3. Inspirations and Suggestions for the Management of Large Old Tree Resources

As the political, economic, and cultural center of China, Beijing still retains 40,590 large old trees with the rapid growth of the social population, rapid economic development, and aggravation of urbanization. This shows that the threat of urbanization to urban large old tree resources is not inevitable. The distribution of large old trees in Beijing was most closely related to SRHS, demonstrating that urban policy management plays a decisive role in resource management. Research of two cities in California found that municipalities that choose not to proactively plan for and manage their urban forests will encounter higher total costs over the lifespan of trees and may experience a loss of net benefits from urban forests [64]. Therefore, managers should not try to preserve the large old tree resources alone; rather, they should implement plans at a higher level, such as urban management policies, urban rationality, expansion and other aspects, to promote the protection of urban natural resources and historical culture. Second, the economic level is closely related to the distribution of large old tree resources. Therefore, financing should be increased to cover the cost of the management and protection of urban large old tree resources, a large old tree protection foundation should be established, and channels for social donations (especially in cities where the management department is short of funds) should be provided to fund the management and protection of large old trees.

At the urban scale (especially in large cities), the influence of human factors reduces the impact of natural factors on large old tree resources. However, this is not necessarily negative. Residents or managers with a strong awareness of the need to protect large old tree resources can promote the formation of large old tree resources. As many large old trees in the suburbs of Beijing are not under human protection, the number of large old trees is less than that of the heavily urbanized areas. In urban forests, community participation can greatly contribute to ecological protection [65]. This shows that the impact of human factors on large old trees is two-fold, providing a new perspective for the protection of large old tree resources. Urban large old trees can be used to build several large old tree landscapes and publicity activities, promoting economic growth and awareness at the same time. The ecological culture is strengthened, along with the public's awareness of the need to protect large old trees.

Residents plant trees according to their own preferences. Under natural competition, tree species with competitive advantages and longevity survive, but negative human activities destroy their habitats and lead to the decline of large old trees. The research results in a major urban area in Southern Appalachia, USA suggest that homeowners living around urban trees place greater importance on various attributes of trees, and that tree knowledge and experience are indirectly and positively related to support for urban forest protection [66]. Therefore, these large old tree species are excellent native tree species that have undergone natural and artificial selection. They can provide a reference for the selection of tree species in the construction of urban forests considering ecological resistance, public preference, and rich landscape levels. Therefore, in the construction of urban forests, large old tree species can be used to build an urban ecosystem with local characteristics and stable landscape levels.

Finally, the conflict between large old trees and human settlements also needs to be resolved. For example, the canopy of *S. japonicum* has a shading function for residents, but the larger canopy is not suitable for side branches, increasing the risk of breakage and threatening the safety of residents. Therefore, determining the management measures of large old trees through risk assessment is important for alleviating the pressure on urban ecology and building a green and harmonious urban living environment.

5. Conclusions

The main goal of this study was to explore the driving factors of the composition and spatial distribution of large old urban tree resources. Through DCA and GeoD analysis, we found that social factors (SRHS and GDP) were the dominant factors in determining the spatial distribution and species distribution of large old trees in Beijing, and the spatial distribution of large old trees was mainly affected by the SRHS. The SRHS and GDP were the most important factors affecting the richness of large old tree species. The interaction detection results showed that the distribution pattern of large old tree resources in Beijing was affected by a variety of factors. In addition, the functional value of tree species and tree species characteristics determined the distribution of large old tree habitats. We found that urbanization inevitably forms a human-led pattern, leading to the strong social attributes of large old trees or other forest trees in cities. The influence of such social attributes exceeded the impact of other factors on large old trees. Urban protection policies, cultural traditions, residents' educational level, ecological protection awareness and income level and other social factors had positive or negative impacts on the protection of large old trees. Therefore, we suggest that managers should strengthen the protection of large old trees in SRHS, increase the awareness of the protection of big old trees, guide residents to protect big old trees, and provide donation channels for the protection of big old trees. In the construction of urban forests, large old tree species can be used to build an urban ecosystem with local characteristics and a stable landscape level and they can be cultivated as reserve resources for large old trees. In the future, the social attributes of large old trees deserve further in-depth research. Researchers should assess the impact of social factors on the protection of large old tree resources. Managers should not only formulate protection policies but also mobilize society. Residents should work together to protect large old trees. In addition, as a part of the social environment, large old trees also conflict with residents' safety. This is an important issue that researchers and managers should consider in the future.

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