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Evolvement of Spatio-Temporal Pattern and Driving Forces Analysis of Ancient Trees Based on the Geographically Weighted Regression Model in Guangzhou and Foshan, China

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Abstract: Ancient trees play an important ecosystem service role in high-density cities, revealing the zonal distribution characteristics of vegetation under climate influence. The ancient trees in Guangzhou and Foshan in 2018 and 2023 were taken as study objects to explore the evolution of their spatio-temporal patterns and to analyze the spatial differentiation characteristics of their driving factors using the geographical weighted regression (GWR) model. The results showed the following: (1) The ancient trees in Guangzhou and Foshan were composed of typical subtropical evergreen broad-leaved forest communities, mainly represented by broad-leaved species of evergreen dicotyledonous plants. The dominant species mainly included *Litchi chinensis*, *Ficus microcarpa*, *Canarium pimela*, *Ficus virens*, and *Dimocarpus longan*. However, there was a significant difference between Guangzhou and Foshan. (2) The number of ancient trees in Guangzhou showed negative growth, while Foshan saw a significant increase. However, species diversity in both areas increased, with the highest diversity in the northeast, higher diversity in the south-central part, and lower diversity in the western and northwestern parts. (3) The maximum kernel density of ancient trees in Guangzhou and Foshan differed 22-fold, indicating a spatial distribution pattern of multiple clusters. (4) The GWR model effectively explained the driving factors of the heterogeneity of the spatial distribution of ancient trees. The results showed that artificial disturbance was the most important factor affecting the spatial distribution of ancient trees in high-density urban agglomerations in the same vegetation zone. The study clarified the characteristics of the spatial distribution and species diversity of ancient trees in the region, revealed the driving factors for the evolution of the spatial pattern of ancient trees in highly urbanized areas, and provided guidelines for policies and measures for enhancing biodiversity and conserving germplasm resources in the region.

Keywords: ancient trees; evolvement of spatio-temporal pattern; geographical weighted regression models; driving forces; Guangzhou; Foshan

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1. Introduction

Ancient trees are non-renewable heritage produced by the synergistic effects of time, nature, culture, and society, and have important landscape ecology, history and culture, scientific research and education, and economic production value [1,2]. On the one hand, ancient trees are important nodes of ecosystem stability and complexity, playing a key role in maintaining and restoring ecosystem functions [3]. On the other hand, ancient trees are symbols and epitomes of human culture, customs, and history, and are cultural landscape elements that provide cultural benefits, carry memories of places, and stimulate emotional resonance [4–6]. With changes in natural conditions, such as global warming, an increase in extreme weather events, and man-made disturbances, such as the construction of high-density cities and towns, the ecological environment for the survival of ancient trees is becoming increasingly harsh and shrinking, and the number of trees is decreasing sharply [7,8]. The loss of indigenous peoples and the dissolution of traditional relationships have led to a gradual decrease in the number of subjects for the protection of ancient trees [9], and the cultural traditions attached to ancient trees are also dying out in the process [10]. This may lead to the loss of the vegetation germplasm resource base, the loss of regional historical and cultural value, and reduced ecological functions, such as water conservation, carbon sinks, and biodiversity maintenance, resulting in a further imbalance in the regional ecosystem [11]. Therefore, the conservation of ancient trees and their germplasm resources has become a bio-ecological issue that needs urgent attention during urbanization and development of megacities [12]. It will be of great scientific value to explore the spatial and temporal pattern evolution of ancient trees in high-density city regions and their driving forces, thereby enhancing the biodiversity and ecosystem stability of the region [13].

Criteria for naming and assessing trees that have survived for a long time or are culturally relevant vary considerably around the world. Champion trees in countries such as the United States, the United Kingdom, and Canada emphasize tree height, crown, and trunk size [14]. Significant trees in Australia focus on the historical, social, and aesthetic value of trees [15]. Ancient trees in China highlight the age of the tree, and notable trees emphasize the historical, cultural, scientific, and monumental value of the tree [16]. Early studies on ancient trees mainly clarified the types and quantities of regional ancient tree resources through reviewing historical data [17] and conducting field surveys [18] and flora comparisons [19] or predicted the age of ancient trees using increment core sample sections [20], chronotaxis [21], cross-dating with total stations and computers [22], and growth regression modeling [23,24]. With the intensification of global urbanization leading to the gradual fragmentation of ancient tree habitats, the conservation, rehabilitation, and exploitation of ancient tree resources have become important research themes [25,26]. This includes the improvement of standing conditions, disease and pest control, trunk restoration, and the construction of ancient tree parks. In recent years, geographic information systems have been widely applied, and research results on the spatial distribution patterns of ancient trees at different scales, such as national, provincial, municipal, and township scales, are abundant [27–29]. However, studies at a single timescale are predominant, and relatively few studies examine the evolution of spatial and temporal patterns across multiple timescales. The spatial and temporal distribution patterns of ancient trees are the result of the joint influence of multiple processes and factors, and most of the studies [13,30,31] focused on the influence of natural factors, such as elevation, slope, and river, and social factors, such as socioeconomic factors, land use, and population density, neglecting the important role of human factors, such as religious culture and historical and cultural blocks in regions of strong historical and cultural binding. Among the research methods, qualitative induction [32], mathematical statistics [33], grid method [34], and linear regression analysis [35] have been used. However, the influence of external factors on the spatial distribution of ancient trees is not a single linear relationship, and the above methods fail to explore the influence of related factors on the spatial pattern of ancient trees. Therefore, the spatial relationship of the influencing factors must be further explored. Geographically weighted regression (GWR) is a local regression model that explains the local effect of the independent variable on the dependent variable by analyzing the regression coefficients of the independent variables in different spatial locations [36]. It is suitable for the statistical analysis of spatially non-stationary data. Currently, GWR models are widely used in economic and social fields [37,38]; however, little research has been conducted on the spatial and temporal distribution patterns of ancient trees.

With the comprehensive mapping of ancient tree resources in recent years, the data on these resources have been updated and improved. In 2016, Guangdong Province conducted a census and archiving of ancient tree resources, which were completed across the province in 2018. As the core region of the Global 200 ecological zone, mainly characterized by subtropical evergreen broad-leaved forests, Guangzhou and Foshan's suitable climatic conditions, long history and culture, and protection of ancient trees have led to the accumulation of rich ancient tree resources in the region [39]. Studies on ancient trees in Guangzhou and Foshan have mainly focused on resource characterization, conservation and utilization, public awareness of conservation, and health evaluation [40,41]. Although geographically neighboring and culturally homogenous, it has not yet been demonstrated whether ancient tree resource types, spatial distribution patterns, and factors affecting the spatial distribution of ancient tree resources are the same. Therefore, we used the ancient tree resources in Guangzhou and Foshan in 2018 and 2023 as the research objects, quantitatively analyzed their species composition and spatial distribution, and adopted the GWR model to reveal the degree of influence and spatial change rules of multiple factors, such as natural, humanistic, and social factors, on the distribution of ancient trees. The aim of the study was to provide theoretical references for targeting the protection of ancient tree resources in Guangzhou and Foshan and the maintenance of regional species diversity.

2. Materials and Methods

2.1. Study Sites

Guangzhou and Foshan are adjacent geographical regions and birthplaces of the Lingnan culture. The areas have a subtropical monsoon maritime climate, with a mild and humid climate and abundant rainfall. The zonal vegetation includes subtropical evergreen broad-leaved forests. Guangzhou, located at the northern edge of the Pearl River Delta and neighboring Foshan to the west, was founded more than 2000 years ago. It is situated at longitude 112°57′–114°03′ E and latitude 22°26′–23°56′ N, covering a total area of 7434.4 km^2. Its topography is high in the northeast and low in the northwest, with well-developed water systems and numerous rivers. Foshan, founded more than 1300 years ago, is located in the hinterland of the Pearl River Delta, east of Guangzhou. It is situated at longitude 112°22′–113°23′ E and latitude 22°38′–23°34′ N, covering a total area of 3797.72 km^2. Its overall topography is high in the northwest and southwest and low in the center and southeast, with a dense water network. The Xijiang and Beijiang Rivers and their tributaries run throughout the entire territory (Figure 1).

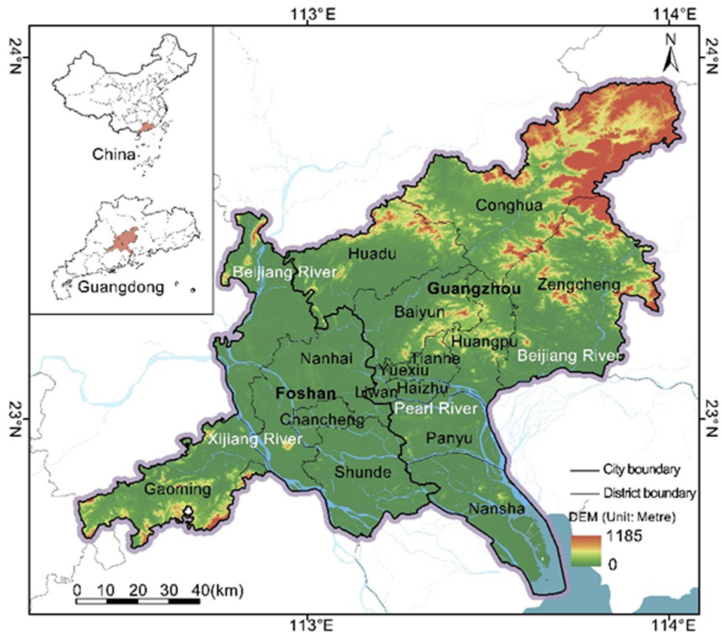

Figure 1. Location map of Guangzhou and Foshan.

2.2. Data Sources

According to the 'Technical Regulation for Surveying of Old and Notable Trees' in China [42], the age of ancient trees in Guangzhou and Foshan in 2018 and 2023 was determined by using a tree ring analyzer combined with the 'three-piece algorithm', which can accurately analyze the age of ancient trees [43,44]. Ancient trees refer to trees with an age of 100 years or more, which can be classified as Class I (a $\geq$ 500), Class II (300 $\leq$ a < 500), and Class III (100 $\leq$ a < 300) according to their age, and trees aged between 80 and 100 years are included in the reserve resources of ancient trees [30].

The Python 3.10 software was used to review the ancient tree data in the Guangdong Provincial Ancient and Famous Trees Information Management System to collect 12,213 and 12,977 surviving ancient trees in Guangzhou and Foshan in 2018 and 2023, respectively, including the number, family, and age of the ancient trees. Samples were collected through field research to verify the accuracy of the data on ancient trees and correct the data on erroneous family genera and species according to the Flora Reipublicae Popularis Sinicae. We compared the ancient tree numbers of the two periods and screened the data of new and dead ancient trees in Guangzhou and Foshan for 2023. All spatial data were unified into WGS_1984_UTM_Zone_49N projections. Table 1 lists the data categories and sources used in the study.

Table 1. Data categories and sources.

Data Categories	Data Sources and Description
Ancient trees data	Information Management System for Ancient and Valuable Trees in Guangdong Province (http://gsmm.lyj.gd.gov.cn, accessed on 18 April 2018, and 5 April 2023.)
Land-use data	Center for Resource and Environmental Sciences and Data, Chinese Academy of Sciences, 30 m resolution
DEM data	Geospatial data cloud, 30 m resolution
Point of interest data	Gaode Map Navigation
Cultural heritage data	Plan for the Protection of Famous Historical and Cultural Cities (2020–2035)
Nature reserve data	Planning of Nature Reserves in Guangdong Province (2021–2035)
Demographic data	LandScan population dataset
Water system and road data	Open Street Map

2.3. Research Methodology

2.3.1. Species Diversity Index

The species diversity index is a composite index of richness and evenness that reflects the differences in community composition and structure in different regions [45]. Based on the distribution data of the number of plants of various types of ancient trees in Guangzhou and Foshan (Table S1), in this study, the Shannon diversity and evenness indices were selected to reflect high or low levels of community diversity and evenness, respectively, of the distribution of different species in the community in Guangzhou and Foshan.

The Shannon diversity index formula is:

$$H = -\sum_{1}^{S} P_i \,(\ln P_i) \tag{1}$$

The evenness index formula is:

$$E = \frac{H}{\ln S} \tag{2}$$

where H is the Shannon diversity index of ancient trees, E is the evenness index of ancient trees, S is the total number of ancient trees in Guangzhou and Foshan, and P_i is the proportion of the ith ancient tree to the total number of ancient trees in Guangzhou and Foshan.

2.3.2. Kernel Density Estimation

Kernel density estimation calculates the density of spatial point elements in the surrounding region to form a continuous density surface that reflects the distribution of elements [46]. From the perspective of the region, ancient trees in Guangzhou and Foshan can be approximated as point elements, and this method can be used to analyze the clustering centers of ancient trees. Its formula is:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (3)$$

where $f(x)$ is the kernel density value of the ancient tree, k is the spatial weight function, $x - x_i$ is the distance between two ancient trees, and h is the bandwidth, that is, the radius of the circle.

2.3.3. Spatial Correlation Analysis

Spatial correlation analysis can be used to study the spatial distribution of ancient trees with high–high neighboring or high–low staggered distributions. The global *Moran's I* index measures whether ancient trees have spatial clustering characteristics [47], and hotspot analysis (Getis-Ord Gi* index) further identifies hotspot regions where ancient trees are clustered [48]. Its formula is:

$$Moran's\ I = \frac{n \times \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \times \sum_{i=1}^{n}(x_i - x_j)^2} \quad (4)$$

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}(d)x_j}{\sum_{j=1}^{n} x_j}(j \neq i) \quad (5)$$

$$Z\left(G_i^*\right) = \frac{G_i^* - E(G_i^*)}{\sqrt{Var(G_i^*)}} \quad (6)$$

where *Moran's I* is the global Moran's index, n is the number of ancient trees, x_i and x_j denote the ancient trees in the ith and jth cells, respectively, $\overline{x}$ is the average of all ancient trees, w_{ij} is the spatial weight matrix, *Gi** is the Getis–Ord hotspot analysis method statistical index, *Z* (*Gi**) is the mathematical expectation, and *Var* (*Gi**) is the coefficient of variation. *Moran's I* > 0 indicates a positive spatial correlation, *Moran's I* < 0 indicates a negative spatial correlation, and *Moran's I* = 0 indicates a random spatial distribution. Positive and negative values of *Z* indicate hot and cold spots, respectively, with higher values of *Z* indicating tighter clustering of hot spots, and vice versa for tighter clustering of cold spots.

2.3.4. Ordinary Least Squares

The ordinary least squares (OLS) model is a global linear regression model [49]. The OLS model was used to test for covariance due to the possibility of multicollinearity among the independent variables, which in turn leads to the failure of the econometric model. Its formula is:

$$y_i = \beta_0 + \sum_{i=1}^{n} \beta_k x_{ik} + \varepsilon_i \quad (7)$$

where y_i is the dependent variable, β_0 is the intercept constant, x_{ik} is the independent variable, β_k is the regression coefficient of the *kth* independent variable, ε_i is the residual, and n is the number of ancient trees.

2.3.5. Geographically Weighted Regression Models

GWR models that combine spatial correlation and linear regression are improved spatial linear regression models [50]. In contrast to the ordinary least squares (OLS) model, this model calculates the parameters of the independent and dependent variables locally rather than globally or averaged, analyzes the relationship between the variables in different geographic locations, and is capable of reflecting local characteristics that have been overlooked [51]. Its formula is:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{n} \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \quad (8)$$

where yi is the dependent variable, β_0 (u_i,v_i) is the intercept, (u_i,v_i) are the latitude and longitude coordinates of the *i*th ancient tree, β_k (u_i,v_i) is the value of the continuous function β_k (u_i,v_i) at *i*, x_{ik} is the observed value of the *kth* dependent variable of the *i*th ancient tree, and ε_i is the residual.

3. Results

3.1. Composition and Spatial Distribution of Ancient Trees in Guangzhou and Foshan

3.1.1. Family and Species Composition of Ancient Trees

In 2018, the total number of ancient trees in Guangzhou and Foshan was 12,213, belonging to 39 families, 74 genera, and 103 species. By 2023, there were 12,977 trees, belonging to 41 families, 80 genera, and 114 species. In terms of the composition of the zone, there were 35 species of subtropical evergreen broad-leaved [52] ancient tree resources, such as Fagaceae, Lauraceae, Theaceae, Hamamelidaceae, Annonaceae, Aquifoliaceae, Moraceae, and Proteaceae, in Guangzhou and Foshan in 2023, totaling 11,012 species, including *Castanopsis hystrix*, *Camphora officinarum*, *Schima superba*, and *Liquidambar formosana*. Searching the Information System of Chinese Rare and Endangered Plants (ISCREP) revealed 16 species of rare and endangered ancient trees in Guangzhou and Foshan, including Ginkgo biloba, *Glyptostrobus pensilis*, *Pterospermum heterophyllum*, and *Toona ciliata*, totaling 274 trees. The dominant families of ancient trees in Guangzhou and Foshan were Sapindaceae, Mulberry, Olivetaceae, and Bombacaceae, and the top five dominant species in terms of numbers were *Litchi chinensis*, *Ficus microcarpa*, *Canarium pimela*, *Ficus virens*, and *Dimocarpus longan*.

The total number of ancient trees in Guangzhou in 2018 was 10,120, belonging to 35 families, 62 genera, and 89 species. By 2023, there were 10,005 trees, belonging to 35 families, 65 genera, and 93 species. The dominant families were Sapindaceae, Moraceae, and Burseraceae. In terms of spatial distribution (Figure 2), Sapindaceae were concentrated in the Huangpu District, Moraceae had a wider distribution in all districts of the city, and Burseraceae were concentrated in the Zengcheng District. As shown in Table S1, the number of ancient trees of different species in Guangzhou varied greatly, with the dominant species being *Litchi chinensis*, *Ficus microcarpa*, *Canarium pimela*, *Erythrophleum fordii*, and *Bombax ceiba*, and the share of the city region decreased from 86.31% to 85.63% in 2018–2023.

In 2018, the total number of ancient trees in Foshan was 2093, belonging to 30 families, 43 genera, and 51 species. By 2023, the total number of trees was 2972, belonging to 33 families, 51 genera, and 63 species. The dominant families were Moraceae, Sapindaceae, and Malvaceae. In terms of spatial distribution (Figure 2), mulberry was evenly distributed throughout the city, whereas Sapindaceae and Bombacaceae were mainly distributed in the eastern part of the city. As shown in Table S1, the dominant species in Foshan were *Ficus microcarpa*, *Ficus virens*, *Dimocarpus longan*, *Bombax ceiba*, and *Syzygium nervosum*, with the share of the city decreasing from 89.68% to 87.48% over the five years.

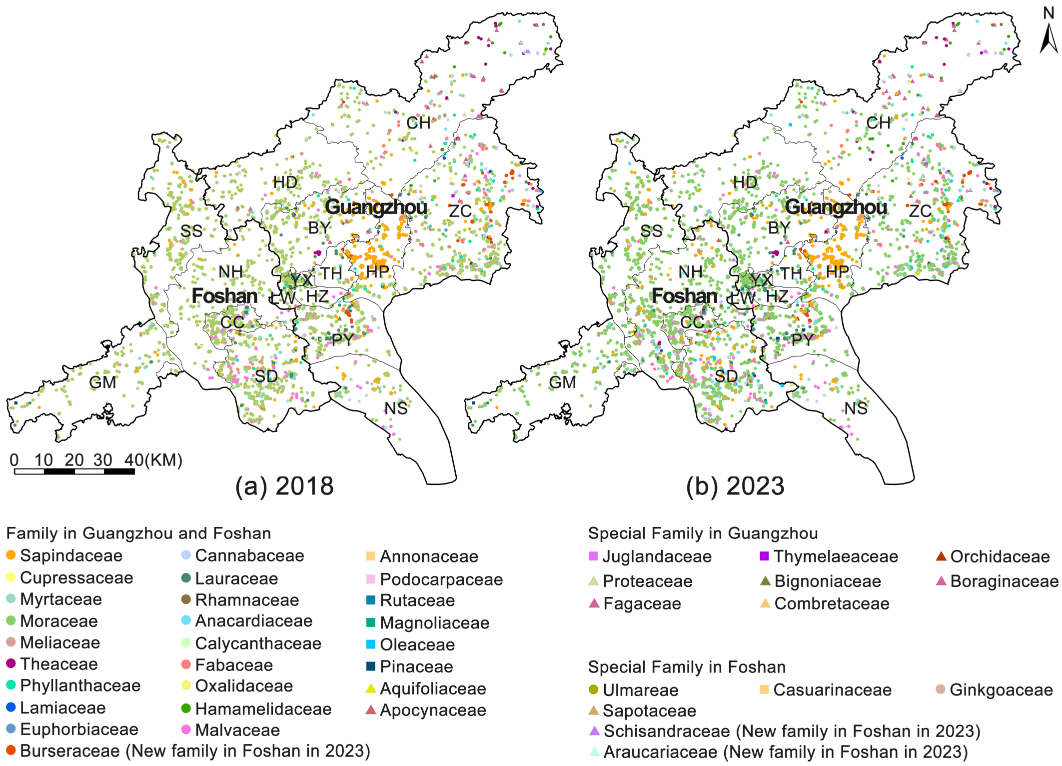

Figure 2. Spatial distribution of ancient trees by family.

3.1.2. Age Distribution of Ancient Trees

The average age of ancient trees in 2018 and 2023 was 151.50 years and 155.43 years in Guangzhou, and 139.77 years and 136.63 years in Foshan, respectively. In terms of spatial distribution (Figure 3), overall, the age of ancient trees in Guangzhou and Foshan exhibited the characteristic of being higher in central areas and lower in surrounding regions. In 2023, the spatial distribution of ancient trees in Guangzhou did not change significantly. The highest age recorded was 1312 years for a *Derris alborubra* in the Zengcheng District. The central urban area of Foshan has a significantly higher number of Class II ancient trees. The oldest tree recorded was a *Ziziphus mauritiana* located in the Shunde District, estimated to be 810 years old.

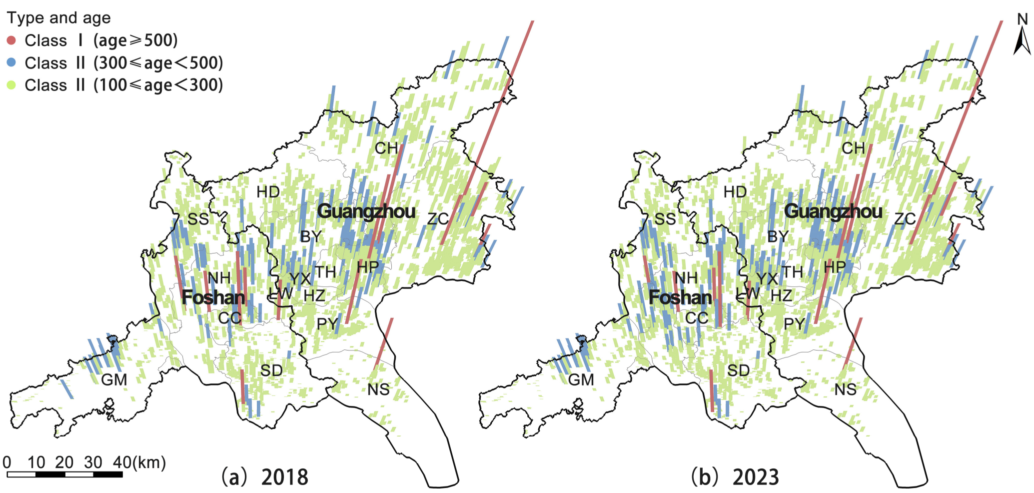

Figure 3. Spatial distribution of age of ancient trees.

3.1.3. Changes in the Increase or Decrease of Ancient Trees

During the five years, 117 ancient trees were added, and 230 died in Guangzhou, with a growth rate of −1.1%; meanwhile, 919 were added and 40 died in Foshan, with a growth rate of 42.0%. In terms of spatial distribution (Figure 4), the new ancient trees in Guangzhou were mainly distributed in the ancient tree groups on Dakeng Hill and in Pen Village, Yunpu Street, and Huangpu District, accounting for 42.3% of the total. Ancient dead trees were concentrated in the Huangpu District, accounting for 92.3% of the total. New ancient trees in Foshan were concentrated in the Nanhai District, accounting for 79.3%, and dead ancient trees were mainly distributed in the Shunde District, accounting for 32.5%. The spatial location of dead ancient trees was determined using the latitude and longitude coordinates of the ancient trees and manual visual interpretation of historical Google satellite images of Guangzhou and Foshan from 2018 and 2023. The land-use type of the location of 56.8% of the dead ancient trees in Guangzhou was converted from woodlands and croplands to construction land, and the land-use type of the dead ancient trees in Foshan was unchanged.

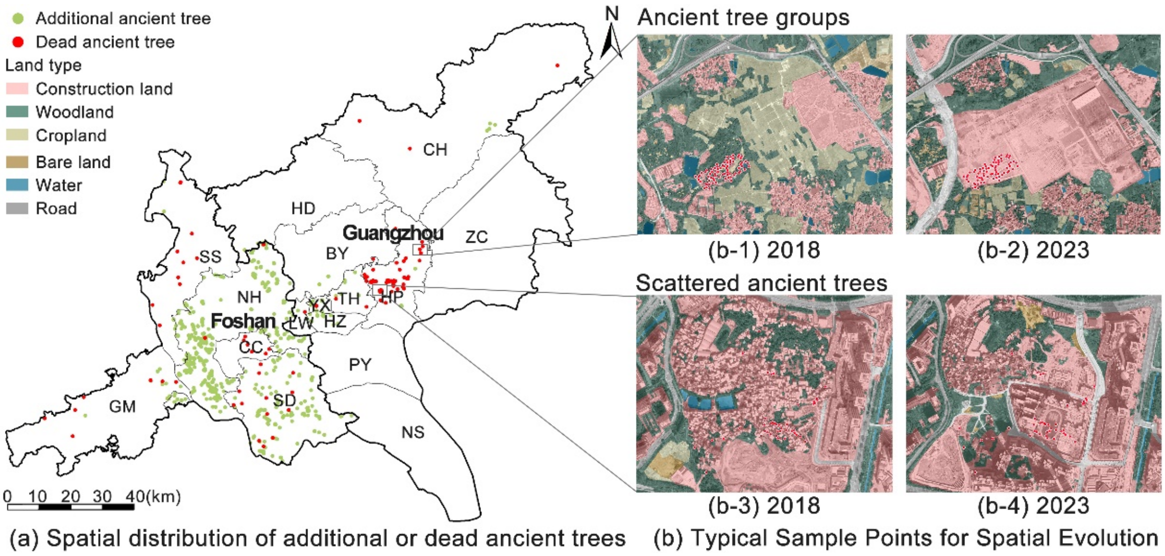

Figure 4. Spatial distribution of new or dead ancient trees and changes in satellite imagery.

3.1.4. Species Diversity of Ancient Trees

The Shannon diversity index (Figure 5a) in Guangzhou and Foshan increased in 2023 compared with that of 2018, and the Shannon diversity index was higher in Guangzhou than in Foshan, indicating that the variety of ancient trees in Guangzhou and Foshan increased and that the species types of ancient trees in Guangzhou were richer. The evenness index (Figure 5b) of Guangzhou was slightly higher in 2023 than in 2018, and that of Foshan was lower than that in 2018. The growth rate of the number of dominant species in Guangzhou in 2023 was −1.92%, and the proportion of dominant species was lower, indicating that the number of ancient tree strains in Guangzhou was more evenly distributed. The dominant species accounted for 75.65% of the new ancient trees in Foshan, and the rare and endangered species only accounted for 0.54%, indicating that the distribution of ancient trees in Foshan was more uneven than that in Guangzhou.

In the city region (Figure 6), both the Shannon diversity and evenness indices in Guangzhou in 2018 and 2023 were characterized by high values in the east and south and low values in the west and north. The high-value region of Guangzhou was richer in ancient tree types, accounting for 69.7% of the total number of species. In contrast, the low-value region was relatively homogeneous in species types, accounting for 47.5%, with *Litchi chinensis* and *Ficus microcarpa* dominating. In 2023, the Shannon diversity index of Nanhai District, Foshan, was higher. The Shannon diversity index of the city region was characterized as high in the southeast and low in the northwest, and the difference in the evenness index of each district was reduced. The ancient tree types in the high-value region of Foshan were extremely rich, accounting for 84.4% of the total number of species. The species types in the low-value region were single, accounting for 21.9%.

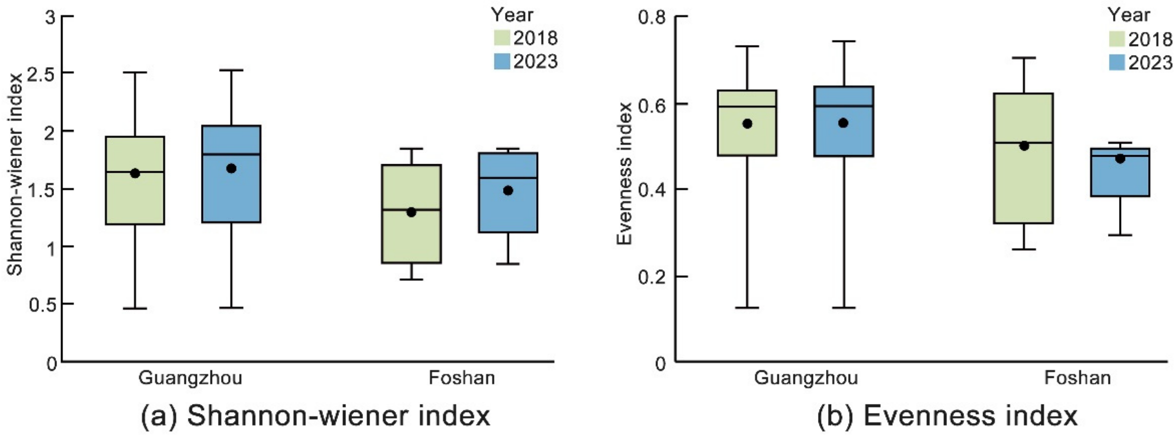

Figure 5. Species diversity indicators of ancient trees in Guangzhou and Foshan.

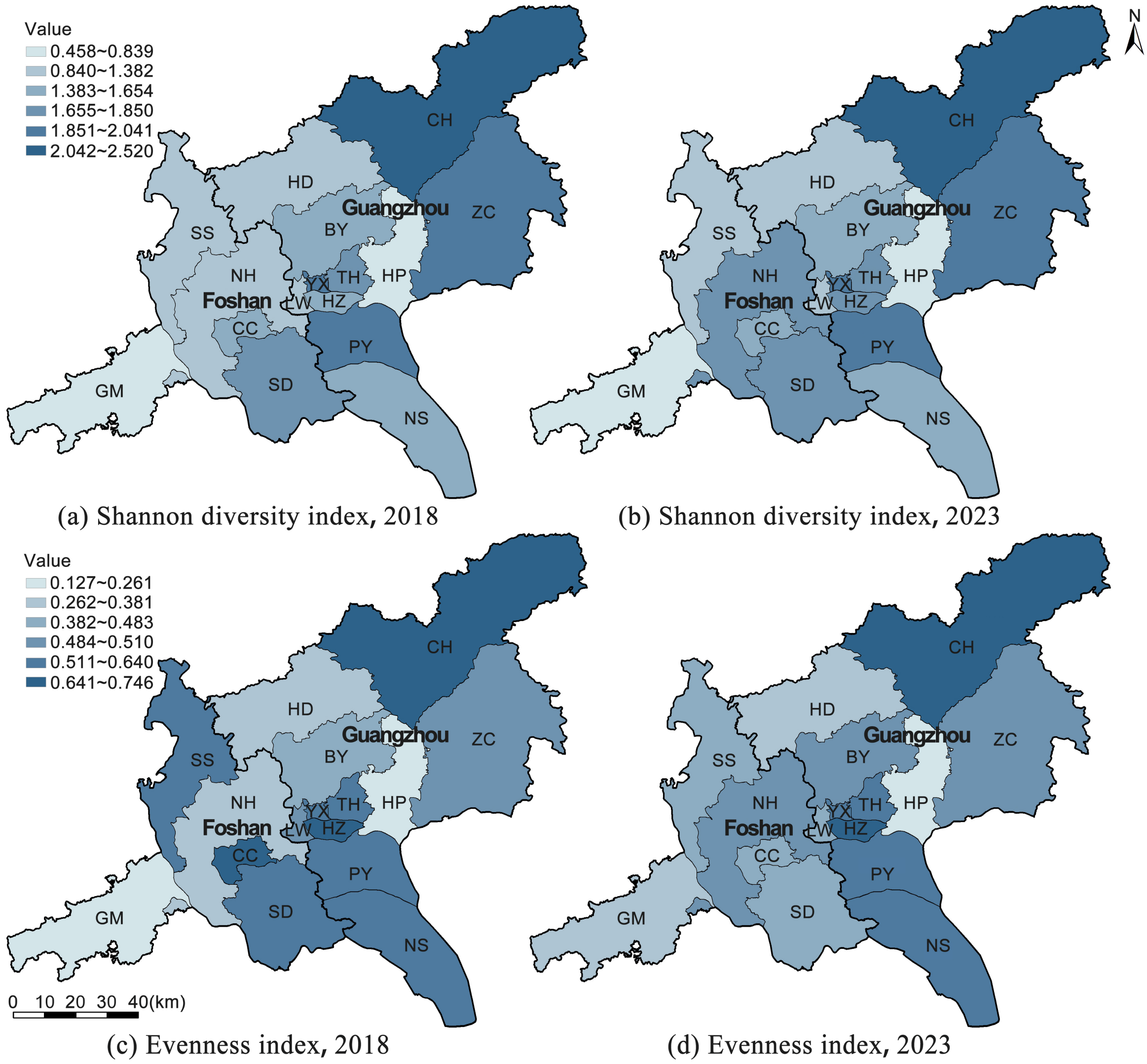

Figure 6. Species diversity indicators of ancient trees in the districts of Guangzhou and Foshan.

3.2. Evolution of Spatial Characteristics of Ancient Trees

3.2.1. Patterns of Spatial Agglomeration

The kernel density tool of ArcGIS10.8 software was used to calculate the spatial distribution density of ancient trees. As can be seen from Figure 7, there was a 22-fold difference in the maximum value of the kernel density of ancient trees in Guangzhou and Foshan, mainly because 56 ancient tree groups existed in Guangzhou, covering 32.3% of the ancient tree resources in the domain, whereas Foshan was dominated by scattered ancient trees. The nuclear density maps of Guangzhou for 2018 and 2023 showed that the spatial patterns were more comparable, with the Huangpu, Panyu, Zengcheng, and Yuexiu Districts as agglomeration centers, forming two high-density agglomeration belts extending in a southwest–northeast direction. Between 2018 and 2023, the maximum kernel density in Guangzhou decreased from 104.559 to 91.943 plants/km^2, and the extent of the two high-density central districts of Huangpu and Zengcheng was reduced by 31.6% and 83.5%, respectively.

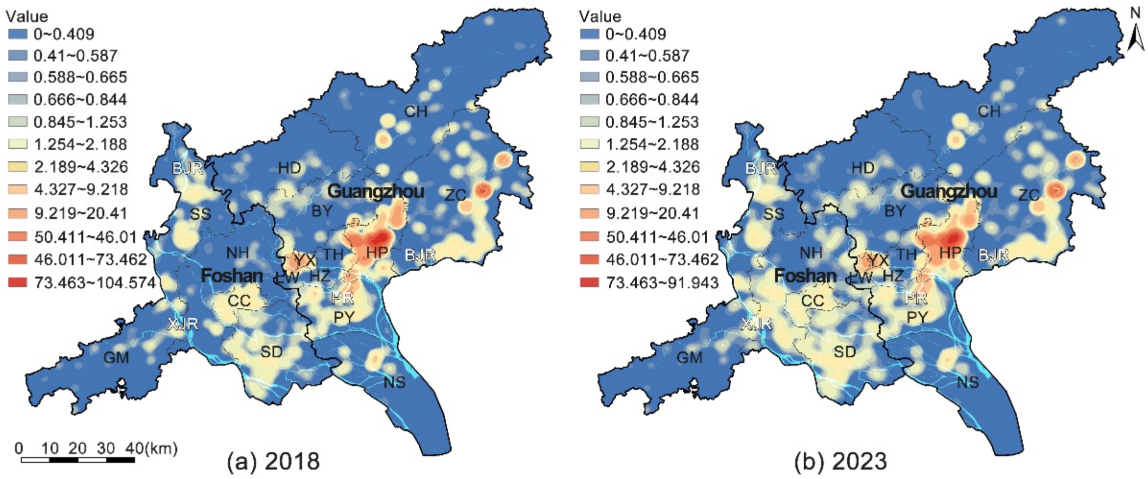

Figure 7. Kernel density estimation of ancient trees in Guangzhou and Foshan.

Compared with the high-density agglomeration pattern of Guangzhou, the ancient trees were more evenly distributed in Foshan. In 2018, the agglomeration centers in Foshan were mainly located in Chancheng District, Sanshui District, and the central part of Shunde District, showing a spatial distribution pattern of multiple groups. The degree of agglomeration in the Nanhai District of Foshan was enhanced in 2023, forming a belt-shaped high-density agglomeration zone extending in a southeast–north direction, overlapping with the course of the Xijiang and Beijiang Rivers (Foshan section). Statistics on the shortest distance between ancient trees and neighboring water systems in Foshan revealed that the number of plants with a distance < 500 m accounted for 62.5%, indicating that ancient trees in Foshan were characterized by waterfront distribution, dominated by *Ficus microcarpa* and *Ficus virens*.

3.2.2. Spatial Autocorrelation Analysis

Guangzhou and Foshan were divided into 2606 and 621 villages or community streets, respectively, to count the number of ancient trees in each region. The global spatial autocorrelation of the number of ancient trees was analyzed using ArcGIS 10.8 software. The results (Table 2) showed that *Moran's I* indices in Guangzhou and Foshan were all > 0, the Z-values were all > 2.58 (the critical value), and the p-values were all < 0.01, indicating that they passed the 99% significance test. There was a significant positive correlation in the spatial distribution of ancient trees in Guangzhou and Foshan. In terms of temporal changes, the global *Moran's I* index and Z score decreased, reflecting reduced spatial correlation and clustering of ancient trees in Guangzhou and Foshan.

Table 2. Global *Moran's I* index for ancient trees, 2018 and 2023.

City	*Moran's I* Index		*Z*-Value		*p*-Value	
	2018	2023	2018	2023	2018	2023
Guangzhou	0.3468	0.3449	37.5950	33.5120	<0.01	<0.01
Foshan	0.4234	0.1701	40.7015	7.0351	<0.01	<0.01

ArcGIS 10.8 software was used to study the spatial correlation and degree of spatial difference between the study units and neighboring regions in Guangzhou and Foshan. This is shown in Figure 8. The localized clustering characteristics of ancient trees in Guangzhou and Foshan were remarkable. In 2018, high–high agglomeration was mainly distributed in Huangpu District, Guangzhou, Zengcheng District, Sanshui District, and Foshan, and low–low agglomeration was mainly distributed in the western part of Guangzhou, Nanhai District, and Foshan. Nine new high–high agglomerations were added in the western part of Nanhai District and Foshan in 2023. From 2018 to 2023, more than 700 ancient tree reserves in Nanhai District, Foshan, were included in the third level of ancient trees owing to the growth in age, and 70.9% were distributed in the west, leading to an increase in the degree of ancient tree clustering in the western part of Nanhai District.

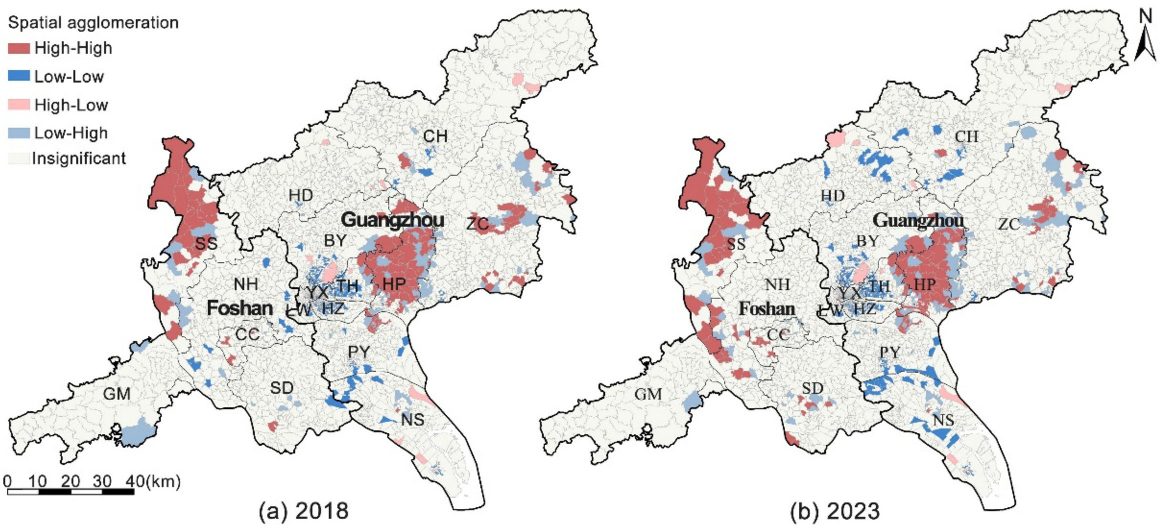

Figure 8. Characteristics of spatial agglomeration of ancient trees in Guangzhou and Foshan.

3.3. Analysis of Differences in the Spatial Distribution of Ancient Trees

3.3.1. Driver Selection

Combining the previous studies [31,53–55] and the situation of Guangzhou and Foshan, based on the data of ancient trees in 2023, 25 driving factors were preliminarily selected to analyze the driving force of the distribution of ancient trees from three aspects: natural, humanistic, and social (Table 3). This study utilized the OLS model to test the multiple covariance of the drivers and to screen out drivers with a p-value < 0.05, that is, those that passed the 95% significance test, to exclude the stronger linear relationship between the drivers and improve the model fit. The results showed that the variance inflation factor (VIF) value of the slope was >7.5, indicating it is a multicollinearity problem in the model; thus, the redundant factors were excluded, and the OLS analysis was re-conducted. The VIF value of the remaining 24 driving factors was <7.5, meaning that the linear relationship between the driving factors was weak, and the GWR model analysis was feasible.

Seven factors, i.e., elevation, geological environment, nature reserves, woodlands, artificial disturbance, economic intensity, and educational resources, passed the 95% significance test for Guangzhou. Seven factors, i.e., growing environment, nature reserves, wetlands, immovable cultural heritage, historical and cultural blocks, urban roads, and artificial disturbances, passed the 95% significance test for Foshan, indicating that the above-mentioned driving factors significantly influenced the spatial distribution of ancient trees in Guangzhou and Foshan.

Table 3. Description of driving factors.

Category	Driving Factor (Units)	Meaning
Natural factor	Elevation (m)	Average elevation
	Slope (°)	Average slope
	Attenuation (°)	Average attenuation
	Distance to a water source (m)	Average minimum distance of ancient trees from rivers, canals, impoundments, and wetlands
	Soil texture	Higher average topographic moisture index indicates higher soil moisture, which is categorized into clayey, loamy, and sandy soils according to the level of the index
	Soil permeability	Soil permeability scores (scores of 9, 7, 5, 3, and 1 were assigned to the loosest, looser, medium, tighter, and most compact soils, respectively, and scores were tallied for each region)
	Geologic environment	Geohazard risk score (scores of 5, 3, and 1 were assigned to low, medium, and high susceptibility to geohazards, respectively, counting risk scores for each region)
	Growing environment	Growing environment score (5, 3, and 1 were assigned to good, medium, and poor growing environments, respectively, tallying the score for each region)
	Nature reserves (%)	Percentage of the region covered by nature reserves
	Wetlands (%)	Percentage of the region covered by wetlands
	Woodlands (%)	Percentage of the region covered by woodlands
	Croplands (%)	Percentage of the region covered by croplands
	Orchard (%)	Percentage of the region covered by orchards
Human factor	Travel sight (pcs)	Number of tourist attractions
	Religious culture (pcs)	Number of shrines, temples, palaces, and churches
	Unmovable cultural heritage (pcs)	Number of stone carvings, ancient tombs, ancient sites, ancient buildings, historical buildings, and important historical heritage and representative buildings of modern times
	Historical and cultural blocks (pcs)	Number of historical and cultural blocks
	Ancient village (pcs)	Number of ancient villages at the national and provincial levels
Social factor	Distance from roads (pcs)	Average minimum distance of ancient trees from urban roads
	Artificial disturbance (pcs)	Number of ancient trees for which aboveground protection or conservation and rehabilitation measures have been implemented
	City parks (pcs)	Number of city parks
	Funeral land (pcs)	Number of cemeteries, mausoleums, and funeral parlors
	Economic intensity (pcs)	Number of hotels, transportation, shopping malls, homes, and businesses
	Educational resources (pcs)	Number of kindergartens, elementary schools, secondary schools, vocational and technical education centers, and higher education and adult education centers
	Population density (people/km^2)	Average population density

GWR analysis was performed using GWR4.0 software, with bandwidth selection corrected using the Akaike information criterion (AICc). The results showed that the explanatory ability of each driver on the dependent variable in Guangzhou and Foshan was 75.5% and 84.1%, respectively, which explain the role and spatial variability of the drivers' influence on the spatial distribution patterns of ancient trees (Table 4).

Table 4. Degree of fit of the GWR model.

City	AICc	R^2	Calibration R^2
Guangzhou	6936.626	0.874	0.755
Foshan	798.757	0.873	0.841

3.3.2. Driving Factor Analysis Based on the GWR Model

The regression coefficients of each driving factor affecting the spatial distribution of ancient trees in Guangzhou and Foshan are detailed in Table 5. Comparing the absolute value of the mean value of the regression coefficients indicated that the factors affecting Guangzhou were artificial disturbance > elevation > geological environment > educational resources > nature reserves > economic intensity > woodlands. The factors affecting Foshan were artificial disturbance > historical and cultural blocks > distance from roads > nature reserves > immovable cultural heritage > wetlands > growing environment. From the mean value of the regression coefficients, the correlation between the nature reserves in Guangzhou and Foshan was negative and positive, respectively, indicating differences in the relationship and degree of influence of the same factor on the spatial distribution of ancient trees in Guangzhou and Foshan. The regression coefficients of the driving factors were analyzed using the natural discontinuity method in ArcGIS 10.8 software (Figure 9) to explore the spatial differences of the driving factors on the spatial distribution of ancient trees in Guangzhou and Foshan.

Table 5. Regression coefficients of drivers.

Driving Factor	Guangzhou				Foshan			
	Min.	Median	Max.	Mean	Min.	Median	Max.	Mean
Elevation	−39.048	16.617	246.103	37.592	—	—	—	—
Geological environment	−107.610	−5.685	10.445	−30.890	—	—	—	—
Growing environment	—	—	—	—	−1.930	−0.028	2.231	0.122
Nature reserves	−45.534	−1.444	8.083	−9.602	−6.016	−0.199	5.449	0.637
Wetlands	—	—	—	—	−1.985	−0.231	1.230	−0.364
Woodlands	−281.299	9.734	107.902	6.758	—	—	—	—
Immovable cultural heritage	—	—	—	—	0.000	0.469	1.240	0.540
Historical and cultural blocks	—	—	—	—	−1.257	4.727	10.007	5.052
Distance from roads	—	—	—	—	−1.362	3.400	8.227	3.294
Artificial disturbance	0.000	42.407	173.512	59.236	0.000	4.826	7.760	5.081
Economic intensity	−19.479	11.584	83.296	7.886	—	—	—	—
Educational resources	−4.202	10.838	53.532	18.741	—	—	—	—

"—" Indicates that this driver did not pass the significance test.

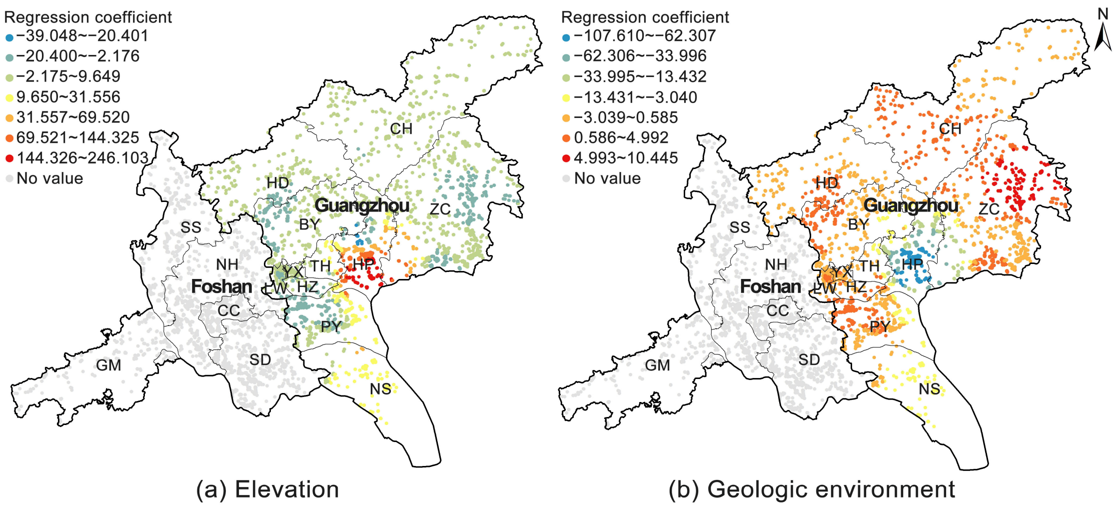

Figure 9. *Cont.*

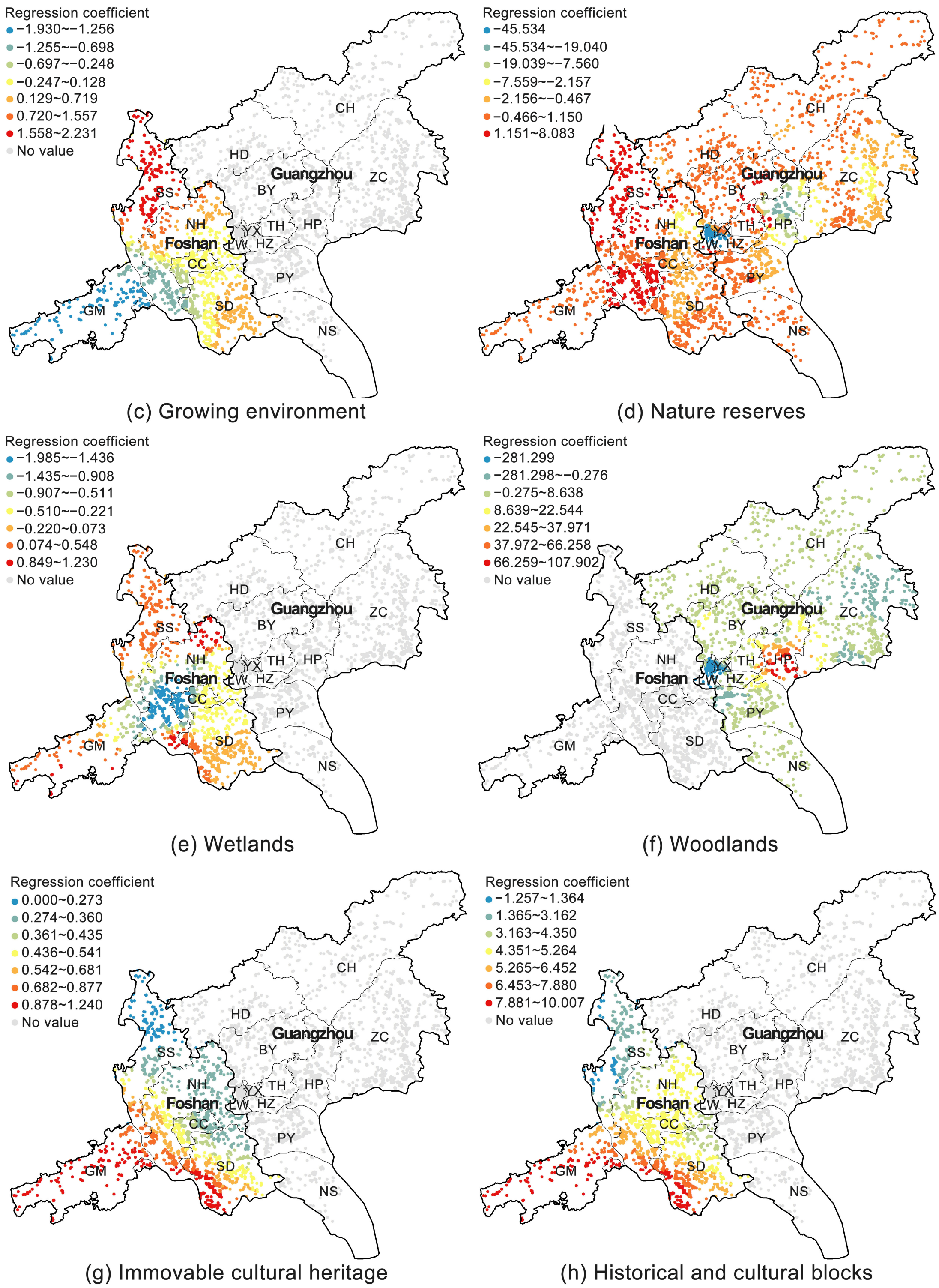

Figure 9. *Cont.*

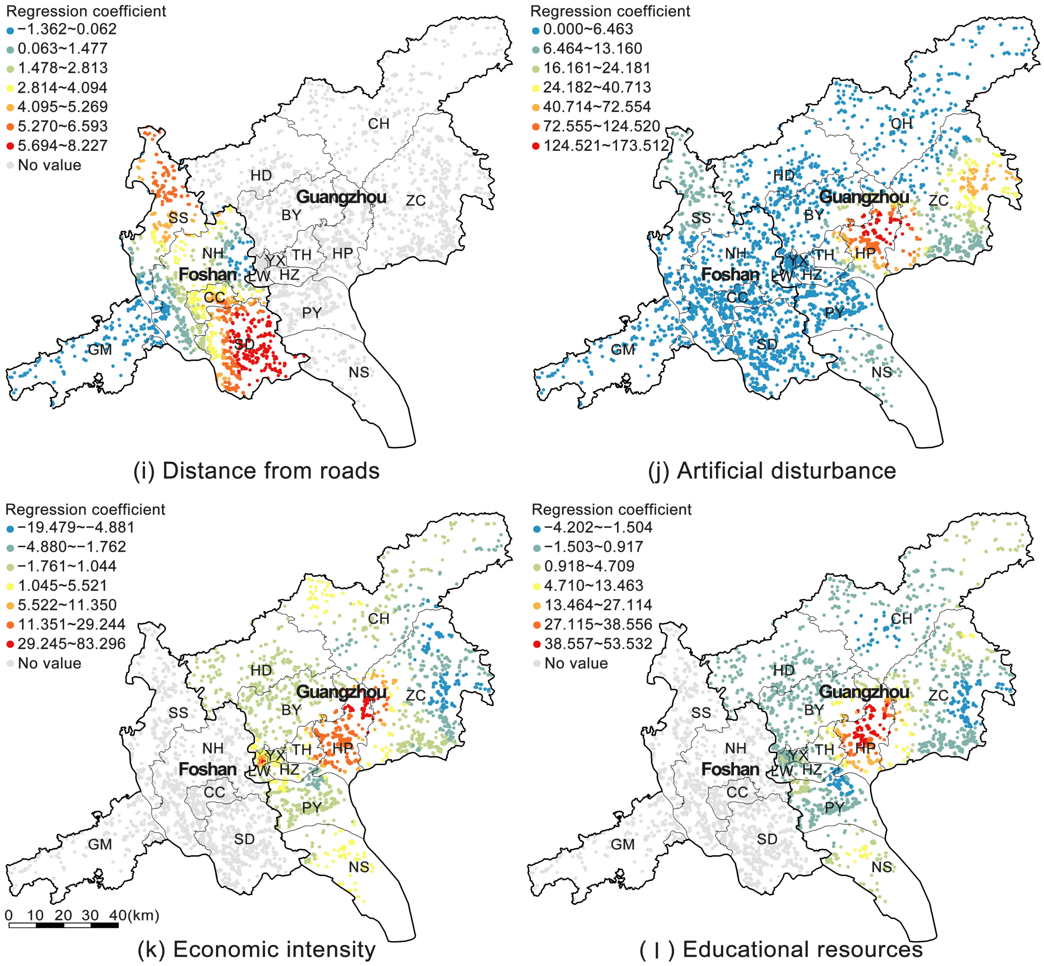

Figure 9. Spatial distribution of regression coefficients of drivers in the GWR model.

3.3.3. Analysis of Factors Influencing the Spatial Differentiation of Ancient Trees

The regression coefficients between the municipalities in Guangzhou and Foshan were significantly different. The analysis of the driving factors of the spatial distribution pattern of ancient trees is detailed in Table 6.

Table 6. Analysis of factors influencing spatial differentiation.

Driving Factor	Guangzhou	Foshan
Elevation	The regression coefficient was high in the center and low in the surrounding region, and the high-value region was mainly distributed in Huangpu District. The southern part of the region is dominated by hilly terraces, and the complex topographic conditions limited the disorderly expansion of towns and reduced the intensity of human activities, which is conducive to protecting ancient trees.	Failed 95% significance test
Geologic environment	The regression coefficient was low in the center and high in the surrounding area. Negative areas were concentrated in the south-central part of Huangpu District. In total, 88 soil collapses accumulated in Huangpu District from 2016 to 2020 [56], the geological environment was poor, and the risk to ancient trees was high. The district government set up inspection teams and used sensors and monitoring probes to understand the growth of ancient trees in real-time. Therefore, although geological disasters occur frequently, ancient tree resources are still retained.	Failed 95% significance test

Table 6. *Cont.*

Driving Factor	Guangzhou	Foshan
Growing environment	Failed 95% significance test	The regression coefficient was high in the east and low in the west, and the high-value regions were mainly distributed in Sanshui and Shunde Districts. This region has less external intervention in the growth of ancient trees and a good growth environment, providing stable growth space for ancient tree resources.
Nature reserves	The regression coefficient was low in the west and high in the east, and the negative regions were located in Liwan and Huangpu Districts. Only 4.7% of the ancient trees were distributed within the scope of nature reserves, while most of the ancient tree resources in Huangpu and Liwan Districts were not assigned to the scope of nature reserves for the time being. There were vacancies in nature reserves, resulting in a negative correlation between the spatial distribution of ancient trees and nature reserves.	The regression coefficient was high in the center and low in the surrounding region, and the high-value regions were located in Nanhai and Sanshui Districts. Ancient trees distributed within the scope of nature reserves accounted for 6.2%. Nature reserves broadened the scope of protection of ancient trees, which helps with their growth and development and maintenance and rejuvenation.
Wetland	Failed 95% significance test	The regression coefficient was low in the center and high in the surrounding region, and the high-value region was located in Sanshui District. There are 9981.56 hm^2 of wetlands existing in this region, distributing water- and moisture-tolerant ancient tree resources, mainly *Ficus microcarpa*.
Woodlands	The regression coefficient was high in the center and low around, and the high-value region was distributed in Huangpu District. Woodlands are the best original land type for the survival of ancient trees, and there are more than 10,000 mu of ancient *Litchi chinensis* over 100 years old in the region, mostly in the top successional communities, which have a certain buffering power against external disturbances.	Failed 95% significance test
Immovable cultural heritage and historical and cultural blocks	Failed 95% significance test	The regression coefficient was high in the south and low in the north, with high-value regions distributed in Gaoming and Shunde Districts and negative value regions distributed in Sanshui District. As an important element of the historical and cultural blocks in Gaoming and Shunde Districts, ancient trees are better protected and utilized under the drive of holistic and original conservation.

Table 6. *Cont.*

Driving Factor	Guangzhou	Foshan
Distance from roads	Failed 95% significance test	The regression coefficient was high in the north and south and low in the center, with the high-value regions located in Shunde, Sanshui, and Chancheng Districts. Major urban roads continuously reduce the growth space of ancient trees, resulting in the weakening or even death of roadside ancient trees. The existing ancient trees in this region are far from the main urban roads, and 66.76% of them further than 20 m away from the urban roads.
Artificial disturbance	The regression coefficients were high in the southeast and low in the northwest, and the high-value regions were distributed in the east of Huangpu and Zengcheng Districts. There are a large number of ancient *Litchi chinensis* groups and ancient *Canarium pimela* groups in this region. As ancient tribute orchards, most of the ancient trees have aboveground protection measures, such as tree pools and supports, which provide a more stable growing environment.	The regression coefficient was high in the north and low in the south, with the high-value region distributed in Sanshui District. Its ancient trees are mainly distributed in villages, schools, and residential compounds due to the fact that the ancient tree resources represented by *Ficus microcarpa* are worshipped as tree gods and are strictly protected.
Economic intensity	The regression coefficient was high in the center-west and low in the east. The high-value areas were distributed in Liwan and Huangpu Districts, and the negative-value areas were distributed in Zengcheng District. It indicated that the governments of economically developed areas pay more attention to the protection of ancient trees and make the protection stronger through policy measures. The residents have a higher awareness of protection [57], and the probability of being subjected to human damage, pests, and lightning strikes is lower.	Failed 95% significance test
Educational resources	The regression coefficient was high in the center and low around, and the high-value region was distributed in Huangpu District. It indicated that the quality of personnel is higher in regions with rich educational resources, and the protection of ancient trees is better when combined with greening and architectural design.	Failed 95% significance test

4. Discussion and Conclusions

4.1. Discussion

The spatial and temporal evolution of ancient trees within urban areas is a result of a combination of natural conditions and anthropogenic activities, leading to distinct variations in the distribution of ancient tree resources across different regions [58]. It has been shown that climate, topography, and anthropogenic disturbances are the main factors affecting the diversity and density of ancient trees [5,59,60]. Global warming may inhibit the photosynthetic efficiency of heat-sensitive tree species, thereby reducing the energy required for growth [61]. At the same time, climate change may also lead to decreased rainfall and increased drought [62], leading to a decline in the quality of habitats for ancient trees. For example, the Amazon Basin suffered severe drought events in 2005 and 2010, which resulted in the death of hundreds of millions of trees [63]. Existing ancient trees are zonal species that are well adapted and resistant to local climatic and soil environments and can be used as one of the most important bases for demonstrating the type of regional plant communities [64]. Since ancient times, the abundant water and heat conditions in Guangzhou and Foshan have provided a favorable growing environment for the growth of regional vegetation, with abundant ancient tree resources, a representative plant community of typical subtropical evergreen broad-leaved forests that have become an important part of the Global 200 Ecoregions [65]. However, the total number of ancient trees in Guangzhou is nearly five times that of Foshan, and there is a difference of about 20 years in the average age of the trees. On the one hand, Guangzhou and Foshan were founded approximately 900 years apart, with Guangzhou being established after the unification of Lingnan by Emperor Qin Shi Huang in 215 BC, which led to earlier human intervention in the screening and planting of tree species. On the other hand, since the Tang Dynasty (ca. 618 A.D.), *Litchi chinensis* has been planted on a large scale in Guangzhou as a representative fruit species of the Lingnan region [66], and some of the best varieties have been preserved until now, which has become a valuable germplasm repository for modern *Litchi chinensis*. The dominant species in Foshan, such as *Ficus microcarpa* and *Ficus virens*, were only endowed with benevolent and tolerant connotations during the Song Dynasty (960 AD) due to their thick and bushy branches and effective shading, becoming places of communal gathering in villages and symbols of nature worship [67]. Regional cultures of nature worship provide a strong foundation for widespread planting and conservation of ancient trees [4]. For example, thousands of Church Forests in Ethiopia have been preserved intact because they are regarded as 'havens for God's creatures' [68]. In India and parts of Asia (e.g., Bali, Indonesia), the *Ficus benghalensis* is worshipped as a religious shrine for followers of Hinduism, attracting tens of millions of pilgrims every year [5]. As a result, the multiple influences of anthropogenic screening of tree species, the history of agricultural cultivation, and the culture of nature worship have led to a major difference in the number, age, and types of dominant species of ancient trees between Guangzhou and Foshan.

Awareness, policies, and intensity of ancient tree protection largely determine the survival and growth of ancient trees [69]. For example, tropical forests in Central America [70] and temperate forests in western North America [71] generally have low mortality rates of ancient trees due to more stable ecosystems. However, the number of ancient trees is rapidly declining in certain areas, covering forests in the southeastern United States [72] and southern Australia [73], sparse grasslands in Africa [74], and urban centers in Europe [75]. The causes of this phenomenon are varied and include land development, logging activities, fire damage, and human removal. Furthermore, there are parts of the world where the number of ancient trees is increasing, such as the forests of northern Finland and the eastern and western United States [76], as well as parts of tropical ecosystems in Africa [77] and South America [78]. Reduced logging, agricultural land abandonment, and lower fire incidence appear to be driving factors for some of the increases in ancient tree populations. The negative growth in the number of ancient trees in Guangzhou in 2023 is mainly due to the 'Greening and Afforestation Special Action' implemented in Guangzhou from 2020 to 2021, during which a total of 15,864 urban trees were relocated or felled, including more than 10 ancient *Ficus microcarpa* in the People's Park in Yuexiu District, and nearly 100 ancient *Litchi chinensis* in Huangpu District [79]. Conversely, the number of ancient trees in Foshan increased significantly in 2023, mainly due to the supplementary survey of ancient tree resources carried out in Guangzhou and Foshan in 2022, in which the reserve resources of ancient trees meeting the age criteria of ancient trees and their previously omitted ancient trees were recorded into the list of ancient trees together [80], resulting in a larger increase in the number of ancient trees in Foshan. Among them, Guangzhou and Foshan added 4 and 12 previously unrecorded species of ancient trees, such as *Alstonia scholaris*, *Araucaria cunninghamii*, and *Gleditsia sinensis*, respectively, which significantly enhanced the diversity of ancient tree species in the municipal area.

From the perspective of the spatial distribution of species diversity, Conghua District has preserved a large number of subtropical evergreen broad-leaved forest vegetation communities, relying on mountain ranges and hills because of its unique geomorphological features, such as the first peak in Guangzhou, making it the richest region in terms of vegetation species diversity in Guangzhou and Foshan, and the distribution of different species in the communities is relatively even [81]. Although Huangpu District is the most densely populated area with ancient trees in Guangzhou, it has the lowest level of species diversity, which is mainly attributed to the fact that 92.12% of the ancient trees in the area are *Litchi chinensis* and are concentrated in orchards around urban villages. This shows that the tradition of fruit tree planting focuses on single-species cultivation, and conservation directly impacts species diversity [9]. The Nanhai District of Foshan added 728 new ancient trees in 2023, increasing the number of ancient tree species in the region from 14 to 39. This significantly raised the local species diversity of ancient trees. The new ancient trees in Chancheng District and Shunde District are mostly dominant species, and the distribution of ancient tree strains is more uneven, reducing the level of species diversity, to a certain extent.

Despite the deterioration in habitat conditions due to high urbanization, most of the ancient trees have survived well after proper protection. In the old urban areas of Guangzhou, such as Yuexiu and Liwan Districts, where urbanization is basically complete and there is less construction disturbance, the ancient trees are distributed in scattered patches, and the habitats are small but stable, which is conducive to spot protection. The high density of fruit and woodland plantations in the mountains of Huangpu and Zengcheng Districts resulted in a multi-center group distribution pattern of ancient trees in the whole city region. However, a series of policies, such as tree species replacement and the influence of the urbanization process, led to a decreasing trend in the maximum nuclear density of ancient trees in Guangzhou in 2023, with a gradual reduction in the range of the two high-density centers in the Huangpu and Zengcheng Districts. Foshan is dominated by scattered ancient trees, forming a belt-shaped, high-density agglomeration extending in a south–east–north direction, which overlaps with the course of the Xijiang and Beijiang Rivers (Foshan section) and should be related to the protection and construction of the ecological belt in recent years. With Foshan vigorously carrying out governance and restoration of the water environment [82], the ancient tree resources on both sides of the Xijiang and Beijiang River basins have been better protected, forming a spatial distribution pattern of ancient trees in Foshan along the rivers in a band-like distribution.

The spatial distribution of ancient trees in Guangzhou and Foshan is affected by a variety of factors, with seven driving factors affecting Guangzhou in the order of artificial disturbance, altitude, geological environment, educational resources, nature reserves, economic intensity, and woodland, and seven factors affecting Foshan in the order of artificial disturbance, historical and cultural blocks, distance from roads, nature reserves, immovable cultural heritage, wetlands, and growing environment. It can be seen that the degree of influence of artificial disturbance on the spatial distribution of ancient trees was the greatest in Guangzhou and Foshan, suggesting that habitat protection, conservation management, and rejuvenation measures for existing ancient trees are the key to good ancient tree growth, the same results as those of studies in Sweden and Finland, among others [76,83], further corroborating that artificial management can have a significant impact on the ecological niche and distribution of species [84]. Elevation had a lesser effect because more complex mountainous terrain creates a more favorable natural barrier for protecting ancient tree resources [31]. Human factors, such as historical and cultural blocks and immovable cultural heritage, had a greater degree of influence, suggesting that holistic conservation of the environment promotes the conservation and revitalization of ancient tree resources. Natural factors, such as woodlands, wetlands, and geological environments, had a lesser degree of influence because, as the original standing conditions of ancient trees, they are the basic environment in which they grow and develop, and their degree of influence is more similar on a larger scale. Nature education, quality education, and the delineation of nature reserves and policy measures also play more important roles. The results of this study were similar to those in Australia [85] and other places, as well as in Jiangsu [13], Shenzhen [30], and Hainan [86] in China, where the distribution of ancient trees in the above study areas was similarly affected by factors such as woodland, altitude, and artificial disturbance. From the urban perspective, the spatial distribution correlation between traditional villages and ancient trees in Guangzhou and Foshan was not strong, differing from the results of some studies [87]. The reason may be that at present, most of the ancient trees are distributed in the central part of the city or in the woodland, while the traditional villages have gradually weakened and disappeared in the development of high urbanization.

Under the background of high urbanization, how to build the protection mechanism of ancient trees (groups) has become an important issue. In the United States and Japan, the high urbanization rate and the protection of ancient trees are taken into account, and the forest vegetation in cities and surrounding areas is concentrated and linked together to achieve systematic protection and overall protection under the control of laws and regulations, and the tradition of joint protection of ancient trees by a variety of subjects has been formed [54,88]. In Romania, through the 'Find the Oldest Trees' campaign in schools, the location, circumference, and species of old trees are searched and recorded, and through nature education and public participation, the public's needs are met, and their environmental awareness is cultivated. This is achieved through nature education and public participation to meet the needs of the general public and to develop their environmental awareness [89]. Drawing on international experience in the protection of ancient trees, Guangzhou and Foshan should base on factors such as the degree of concentration of ancient trees (groups), the properties of the land on which they are located, geographical and environmental conditions, and the degree of population density. Ancient forests distributed in patches should be included in nature reserves for overall protection. In contrast, scattered ancient trees should focus on protecting their habitats and be subjected to regular medical checkups and maintenance. In addition, based on the current inventory of ancient tree resources, further checks should be made to identify ancient tree groups and scattered ancient trees in primary and secondary forests, fields, and settlements to form ecological patches of ancient trees. Ancient tree belts along rivers, streams, base ponds, and field ridges form ecological corridors integrating blue and green spaces of towns and villages to build an interwoven ecological network.

The composition and spatial distribution of ancient resources in Guangzhou and Foshan result from a multifactorial combination of factors, influenced not only by the main drivers of the previous five years mentioned above but also by long time-series factors, such as climate change. Because certain species may have temperature tolerance limits, such as the *Adansonia digitata* in Africa [90], some of the ancient trees may be at risk of survival due to global warming [91,92]. It is difficult to obtain data on hundred-year-old tree resources because of the large time span. This study did not provide a comparative analysis of the factors influencing the spatial and temporal differentiation of ancient trees with a longer time series. With improvements in relevant data acquisition techniques, in-depth studies should be conducted from the perspectives of the evolution of vegetation communities [93], policies over the years [4,94], typhoon frequency [95], and historical events [96] to improve the explanatory power of drivers of the spatial distribution of ancient trees.

4.2. Conclusions

(1) Ancient trees in Guangzhou and Foshan were mainly represented by broad-leaved species of evergreen dicotyledonous plants. The dominant families were Sapindaceae, Moraceae, Burseraceae, and Malvaceae. The dominant species were *Litchi chinensis*, *Ficus microcarpa*, *Canarium pimela*, *Ficus virens*, *Dimocarpus longan*, *Castanopsis hystrix*, *Camphora officinarum*, *Schima superba*, and *Liquidambar formosana*, belonging to the subtropical broad-leaved evergreen forests, which were representative of the vegetation of this community. They preserved the rare germplasm resources of the plant species in the wild to a certain extent, reflecting the fact that the study area is located in a biodiversity hotspot dominated by subtropical broad-leaved evergreen forests.

(2) The species diversity of ancient trees in Guangzhou and Foshan increased in 2023. However, the number of ancient trees in Guangzhou showed negative growth, while Foshan experienced a significant increase. The Shannon diversity index of ancient trees in Guangzhou and Foshan showed the spatial distribution characteristics of high

in the northeast, higher in the south-central part, and lower in the west and northwest. The distribution of different species in vegetation communities in Sanshui, Chancheng, and Shunde Districts of Foshan tended to be unbalanced, while the conservation status of ancient trees in Nanhai District tended to be better. Conghua District in Guangzhou preserves a large number of subtropical evergreen broad-leaved forest vegetation communities, relying on mountain ranges and hills, and is the area with the richest species diversity of ancient trees in Guangzhou and Foshan.

(3) The kernel density of ancient tree distribution in Guangzhou and Foshan varied significantly, presenting a spatial distribution pattern of multiple clusters. The local clustering characteristics of ancient trees in Guangzhou and Foshan were remarkable, and the 56 existing ancient tree groups in Guangzhou presented a relatively clustered spatial distribution characteristic, which is closely related to the long history and culture of the region. With more than 700 ancient tree reserves in Nanhai District of Foshan being included in the third level of ancient trees due to their age, the concentration of ancient trees in the western part of Nanhai District has increased. Therefore, human-led land-use changes during rapid urbanization will affect habitat quality and spatial differentiation, contributing to changes in the spatial distribution pattern of ancient trees.

(4) The GWR model effectively explained the influence of different driving factors on the heterogeneity of the spatial distribution of ancient trees in a region with highly coordinated natural, cultural, and social conditions. Artificial disturbance was a key factor affecting the spatial distribution of ancient trees in Guangzhou and Foshan. The distribution of ancient trees in Guangzhou was mainly influenced by both social and natural factors, while the distribution in Foshan was mainly driven by a combination of social and historical factors.

This study clarified, to a certain extent, the spatial distribution and species diversity characteristics of ancient trees in the region and provided a basis for the zonal distribution characteristics of vegetation. The precise analysis of the driving factors can effectively guide the conservation of ancient trees. With the changes in natural conditions, such as global warming, the increase in extreme weather events, and the continuous advancement of high-density urbanization, the conservation of ancient trees is facing multiple difficulties. Future research directions could focus on modeling the potential impacts of climate change projections on the survival and growth of ancient trees and exploring the measures and effectiveness of ancient trees' conservation internationally, so as to provide policy and measure guidelines for biodiversity enhancement and germplasm resource conservation in different regions.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/f15081353/s1, Table S1: List of ancient trees in Guangzhou and Foshan, 2018–2023.

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