sustainability

Article

Spatial Distribution and Driving Factors of Old and Notable Trees in a Fast-Developing City, Northeast China

Yibo Yang [1], Guangdao Bao [2], Dan Zhang [1] and Chang Zhai [1,*]

[1] College of Landscape Architecture, Changchun University, Changchun 130022, China; yangyb1999@163.com (Y.Y.); zhangdan@ccu.edu.cn (D.Z.)
[2] Institute of Forest Management, Jilin Academy of Forestry Sciences, Changchun 130033, China; bao-gd@126.com
* Correspondence: zhaic@ccu.edu.cn

Abstract: As a symbol of urban civilization and history, old and notable trees (ONTs) are facing challenges brought by rapid urbanization. Changchun is the fastest growing city in Northeast China, and throughout its development process of over 100 years it has preserved many ONTs. This study investigated all the ONTs in Changchun, and analyzed the species diversity, spatial distribution characteristics, dimension, age, and health status of trees by using ecological index and mathematical statistics, and trying to find out the underlying factors regulating their distribution. The results showed that there were 773 old trees belonging to 25 species and 2 notable trees from 1 species in Changchun. *Pyrus ussuriensis* was the dominant species, followed by *Salix matsudana* and *Ulmus pumila*. The urban area, population density, greening rate, and construction history did not influence the species and quantity of ONTs, while the types of land use and tree protection planning were important factors affecting the richness, diversity, and growth conditions of trees. To explore the potential reasons for their existence, the ONTs' data in Changchun was compared with two nearby cities—Harbin and Shenyang. The comparison indicated that the geographical location and climatic conditions also controlled the distribution of ONTs. The number and dimensions of trees were driven by the history and development process of the city. Our findings suggested that preserving favorable living environments and maintaining a low intensity of human disturbance are critical factors for the survival of ONTs in cities.

Keywords: Changchun; driving factors; ONTs; spatial distribution; species diversity

check for updates

Citation: Yang, Y.; Bao, G.; Zhang, D.; Zhai, C. Spatial Distribution and Driving Factors of Old and Notable Trees in a Fast-Developing City, Northeast China. *Sustainability* **2022**, *14*, 7937. https://doi.org/10.3390/su14137937

Academic Editor: Richard Hauer

Received: 30 May 2022
Accepted: 28 June 2022
Published: 29 June 2022

1. Introduction

Old and Notable Trees (ONTs) are precious natural resources in all natural landscapes [1–4]. ONTs refer to trees more than 100 years old or that have important historical, cultural, scientific, and landscape values as well as commemorative significance [5]. The ONTs play critical ecological roles [6]. There is proof that the aboveground biomass stocks and carbon stocks were driven directly by the proportion of such large-sized trees [7–10], and the ONTs provide ample food and suitable habitat for numerous animals [6,11]. Moreover, they can continue to provide ecological services when they occur in small clusters of trees or as individual trees [12]. In urban areas, the ONTs continue to offer biological benefits and cultural benefits, which represent urban resilience and sustainability [13]. ONTs record the changes in the urban environment, inherit urban history, and give birth to unique urban ecological landscapes [14–16]. However, populations of ONTs are declining in forests at all latitudes [6,12,17,18]. Climate change, natural hazards, and human disturbance all lead to the decline of ONTs [17,19–21]. In particular, ONTs experienced more stress in the fast urbanization environment [22,23], as the roadwork and construction activities [24], the building of commercial districts and residential areas [25], and the low conservation awareness of citizens [26] et al aggravated the ONTs' lost. Therefore, a thorough investigation of ONTs' community composition distribution is necessary to protect the reduced natural features [12]. Moreover, it is necessary to determine the potential influencing factors in terms of establishing targeted fine-scale conservation strategies and novel management actions [12,20], as conserving ONTs remains a unique challenge around the world [27].

Herein, we select Changchun city, one of the fastest developing cities in Northeast China as the representative site, which has had a unique history of invasion. From 1931 to 1945, Changchun was the capital of the Puppet Manchukuo when Northeast China was occupied by Japan. The Japanese began to build metropolis in East Asia, which including urban landscape and green land designs since 1932 [28]. Many trees planted in the Puppet Manchukuo have become old trees now. In the past 40 years, Changchun has experienced rapid urban development [29]. With the continuous increase in the urban population and the gradual establishment of urban infrastructures, the interior space of the city is increasingly crowded, and the living environment of ONTs was thus exacerbated. The discovery of a method to protect and make good use of these precious tree resources has become an urgent necessity.

In this paper, we analyzed the spatial distribution and species composition of ONTs in different city districts and tree-habitats, and counted the tree dimensions, age, and growth status with the help of quantitative plant ecology and statistical techniques. This research attempts to provide a basis for the protection of ONTs through investigating their distribution and pursuing the underlying reasons affecting their existence in the rapidly developing industrial cities. In addition, some useful suggestions are proposed based on the results. The findings are suitable for the cities suffering from or that will experience rapid urbanization who wish to maintain sustainable development. Specifically, the three objectives of this study are: (1) to determine the current distribution of ONTs in Changchun, (2) to explore the reasons of ONTs' abundance in different environments, and (3) to reveal the potential driving factors of ONT patterns by comparing Changchun's data with nearby cities.

2. Materials and Methods

2.1. Study Area

Changchun city (43°05′-45°15′ N; 124°18′–127°05′ E) is the capital of Jilin Province, located in the middle latitude of the Northern Hemisphere, the hinterland of the Northeastern Plain of China [30]. A total of 10 administrative districts comprises the whole city, including Chaoyang District (CYD), Changchun New Area (CNA), Nanguan District (NGD), Kuancheng District (KCD), Lvyuan District (LYD), Automobile Economic and Technological Development Zone (ADZ), Jingyue High-tech Industrial Development Zone (JDZ), Erdao District (EDD), Economic and Technological Development Zone (EDZ), and Lianhuashan Eco-tourism Resort (LER) [31]. The built-up area is 543 km^2, with a population of 4.468 million at the end of 2020. Changchun is located in the warm temperate zone, which is continental monsoon climate area, with an annual average temperature of 7.1 °C, annual precipitation of 662 mm, and annual sunshine duration of 2688 h in 2020 [31]. The altitude is 250–350 m in Changchun, and the main types of soil are black soil, meadow soil, and chernozem soil [31].

2.2. District and Green Space Classification

The diversity and growth status of ONTs were analyzed according to urban districts and tree growth environments [32]. A total of 9 districts (Table S1), including CYD, CNA, NGD, KCD, LYD, ADZ, JDZ, EDD, and LER had ONTs. The growth environment of ONTs were divided into 6 green space types, namely Park Green Space (PGS), Road Green Space (RGS), Square Green Space (SGS), Attached Green Space (AGS), Reginal Green Space (EGS), and Other Green Space (OGS) (Table S2) according to the distribution status of ONTs and the classification standard of urban green space [33].

2.3. Field Survey

In 2019, the College of Landscape Architecture, Changchun University, and the Bureau of Forestry and Gardens of Changchun jointly carried out the investigation of ONTs in Changchun. The ONTs' locations were collected in terms of issuing and gathering information through news media from the Government Greening Office. High-resolution remote sensing images were used to accurately locate ONTs. At each spot, we recorded the coordinates by GPS and measured tree dimensions. Diameter at breast height (DBH) was measured by diameter ruler at 1.3 m in height, tree height was observed by TruPulse 200 (Laser Technology, Inc., Centennial, CO, USA), and tree crown size was measured by tape from two directions (east-west and south-north). The species were grouped into six classes [34], namely signature (>200 trees/species), dominant (100 to 199 trees/species), common (50 to 99 trees/species), occasional (10 to 49 trees/species), rare (2 to 9 trees/species), and solitary (1 tree/species). Tree age was reckoned from local the planting record, available history file, or estimated from the average growth of the same tree species in Changchun.

2.4. Data Analysis

All ONTs were surveyed by complete investigation. According to the growth of ONT's leaves, twigs, and trunks, tree growth potential was classified as normal, weak, heavily weak, and endangered; the specific classification standards [5] are shown in Table S3.

The Species richness (S), Shannon–Wiener index (H′) [35,36], Evenness index (J) [37], and species Importance Value (IV) [38] were used to analyze the difference of tree species' composition by different types of green spaces and different urban areas. The equations are as follows

$$\text{Species richness} = \text{S}, \quad (1)$$

$$\text{Shannon-Wiener index: } \text{H}' = -\sum \text{PilnPi}, \quad (2)$$

$$\text{Evenness index: } \text{J} = \text{H}'/\text{lnS}, \quad (3)$$

$$\text{IV} = (\text{RA} + \text{RD}) \times 100/2, \quad (4)$$

where S was the total number of species in each green space type or each district; pi was the proportion of individuals of i-th species; RA is relative abundance: RA = number of trees in a species/total number of trees in the study area; and RD is relative dominance: RD = basal area at breast height in a species/total basal area in the study area.

For a better understanding of the composition and distribution of ONTs in different areas and habitats, Detrended Correspondence Analysis (DCA) ordination was performed with the R package vegan (CRAN project). Similarity Percentage (SIMPER) analysis was adopted to assess the species differentiation among nearby cities. Prior to SIMPER analysis, the IVs of species were square root transformed and standardized by normalization. SIMPER analysis was performed with PRIMER version 5.0 (Primer-E Ltd., Roborough, UK).

3. Results and Discussion

3.1. General Description of ONTs in Changchun

There were 773 old trees belonging to 25 species and 2 notable trees from 1 species in Changchun (Table 1), which represented 19 genera and 14 families. A total of 764 trees of 24 species were native, and only 11 trees of *Pinus tabulaeformis* var. *mukdensis* were exotic. A total of 2 notable trees of *P. tabulaeformis* var. *mukdensis* were planted by Yi Pu, the last Empire of the Qing Dynasty, at the entrance of the Manchukuo Palace State Council in 1943. The contribution rates of the different species were significantly different. Although there was only 1 signature species, *Pyrus ussuriensis*, this number accounted for 78.58% of the total trees, with an IV up to 77.95, which indicated that *P. ussuriensis* occupied an absolute dominant position among the ONTs in Changchun. In addition, the common species was *Salix matsudana*, where the population and IV accounted for 7.87% and 9.58%, respectively. Furthermore, rare species had the most species abundance but a relatively low tree number, and the solitary species accounted for three times the species abundance of the occasional ones but had the smallest population and IV. *P. ussuriensis*, *S. matsudana*, and *Ulmus pumila* were the three most important species, and the total importance value of these species was 92.21% (the representative photos of the three species are displayed in Figure 1).

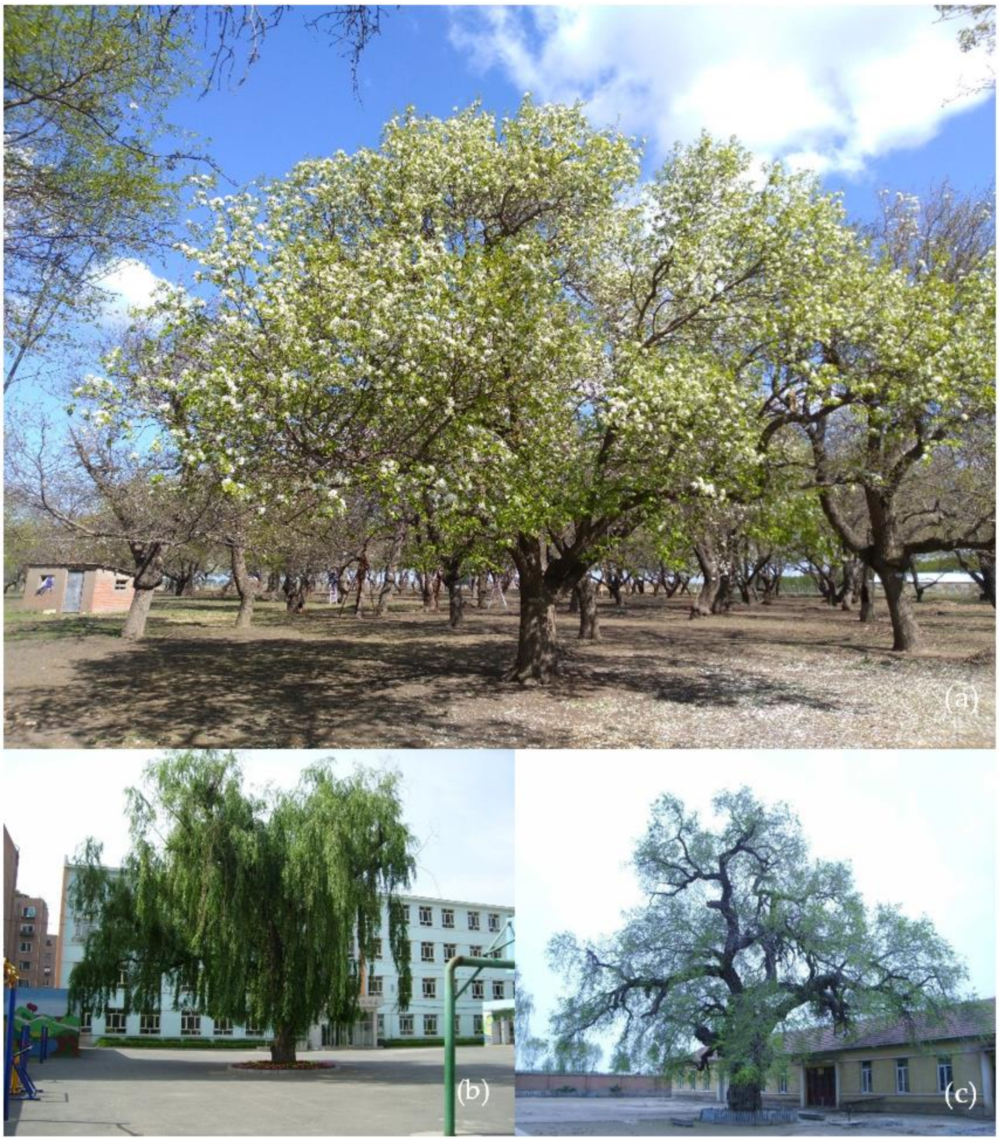

Figure 1. Photos of Old and Notable Trees in Changchun with reference to: (**a**) The ancient pear orchard in LEA of Changchun; (**b**) the 170-year *Salix matsudana* in Changchun NO.7 middle school; (**c**) the 260-year *Ulmus pumila* in Lianhuashan primary school. **Note:** LEA is the abbreviation of Lianhuashan Eco-tourism Resort in Changchun.

Table 1. Species frequency, RA, RD, and IV of Old and Notable Trees in Changchun.

Species	Abundance	Species Frequency	RA (%)	RD (%)	IV
Pyrus ussuriensis	609	Signature	78.58	77.33	77.95
Salix matsudana	61	Common	7.87	11.29	9.58
Ulmus pumila	32	Occasional	4.13	5.24	4.68
Pinus tabulaeformis var. *mukdensis*	11	Occasional	1.42	0.96	1.19
Prunus sibirica	11	Occasional	1.42	0.95	1.18
Quercus mongolica	9	Rare	1.16	0.91	1.04
Malus baccata	6	Rare	0.77	0.38	0.58
Crataegus pinnatifida	4	Rare	0.52	0.41	0.46
Taxus cuspidata	6	Rare	0.77	0.05	0.41
Maackia amurensis	3	Rare	0.39	0.30	0.34
Juglans mandshurica	3	Solitary	0.39	0.29	0.34
Picea koraiensis	3	Rare	0.39	0.20	0.29
Prunus padus	2	Rare	0.26	0.25	0.26
Salix matsudana var. *matsudana* f. *umbraculifera*	1	Solitary	0.13	0.34	0.24
Phellodendron amurense	2	Rare	0.26	0.20	0.23
Acer pictum	2	Rare	0.26	0.20	0.23
Pinus koraiensis	2	Rare	0.26	0.10	0.18
Salix babylonica	1	Solitary	0.13	0.24	0.18
Tilia amurensis	1	Solitary	0.13	0.12	0.12
Fraxinus mandshurica	1	Solitary	0.13	0.11	0.12
Gleditsia japonica	1	Solitary	0.13	0.08	0.11
Prunus mandshurica	1	Solitary	0.13	0.07	0.10
Juniperus rigida	1	Solitary	0.13	0.08	0.10
Morus alba	1	Solitary	0.13	0.05	0.09
Abies nephrolepis	1	Solitary	0.13	0.06	0.09
Total	775		100	100	100

3.2. Spatial Distribution and Floristic Composition by Districts and Green Space Types

The numbers and species of ONTs vary greatly among different urban districts and green space types (Figures 2 and 3). Although CNA and LER had only 3 ONT species, they ranked the first (497 trees) and second (120 trees) place of the total tree number. This was because of the late establishment of these two districts (Table S1), which can better preserve the pear orchards built during Jiaqing Period (1796 to 1820 A.D) in the Qing Dynasty (Figure 1a). These trees were more than 200 years old, and most of them were growing well. Now they have become a tourist attraction for Changchun citizens to enjoy flowers in the spring and pick fruits in the autumn. The number and species of ONTs in ADZ were the lowest, with only three trees belong to two species. Before the establishment of ADZ, most of the land types were farmland and wasteland. Due to the villagers' low conservation awareness, few trees could survived naturally. CYD had the most abundant ONT species (18), which was because the two green lands Nanhu Park and Nanhu Hotel are in this district, covering a green area of 308 hm^2. It was indicated that a favorable environment can satisfy the long-term growth of different tree species.

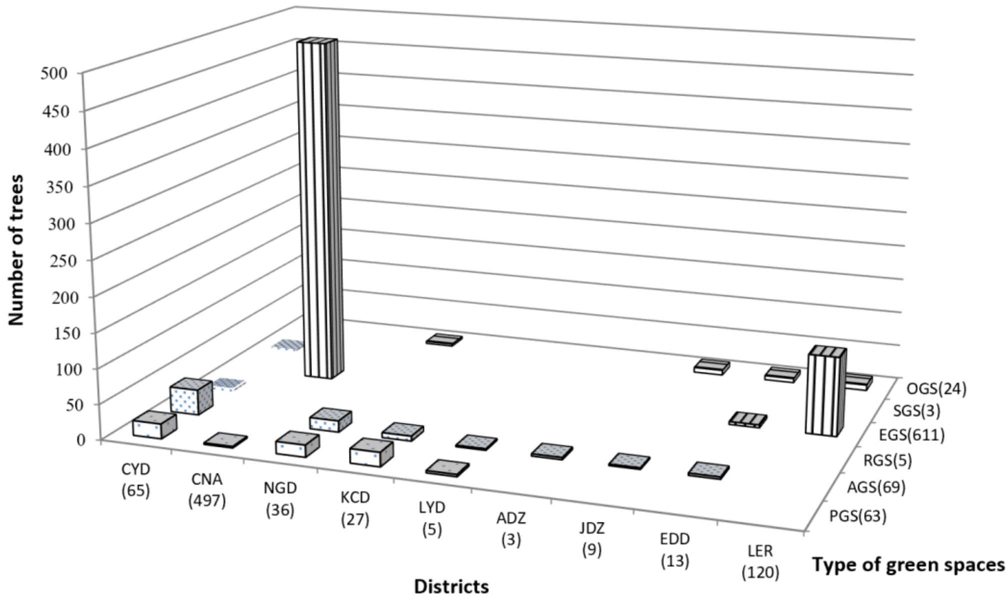

Figure 2. Distribution of the number of trees of Old and Notable Trees by districts and green space types in Changchun. **Note:** Refer to Tables S1 and S2 for the meaning of the abbreviated districts and green space types, respectively. The different bar styles refer to different green space types.

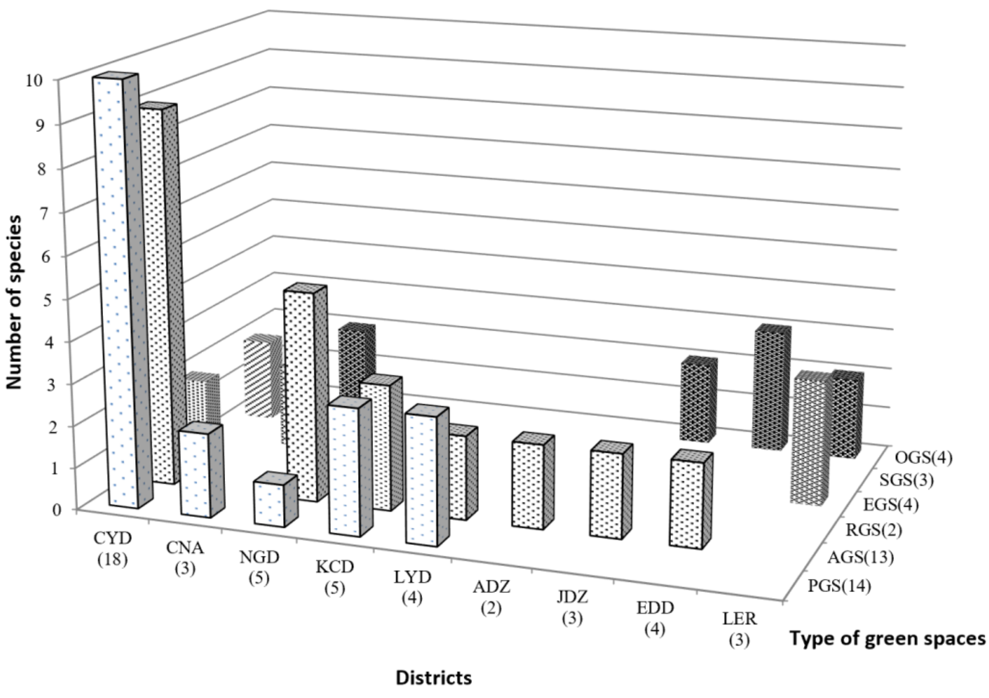

Figure 3. Distribution of species number of Old and Notable Trees by districts and green space types in Changchun. **Note:** Refer to Tables S1 and S2 for the meaning of the abbreviated districts and green space types, respectively. The different bar styles refer to different green space types.

Although there were only 4 ONT species in EGS, the number of trees reached 611, accounting for 78.84% of the total number. This was because the two ancient pear orchards belong to EGS. PGS and AGS were also rich in number of trees and species. Due to their sufficient space and stable types of land use, they can provide a suitable environment for tree growth. RGS and SGS had relatively low ONTs, due to their narrow space, high human disturbance intensity, and poor environmental quality.

The dominant and sub-dominant species of ONTs varied significantly between different urban districts and green space types (Figures 4 and 5). *P. ussuriensis* was the dominant tree species in CNA and LER. As a high-yield native fruit tree, *P. ussuriensis* brings good profits to the owners, so it has been carefully preserved and managed for more than 200 years. *S. matsudana* was the dominant tree species in other districts. This was because *S. matsudana* grows fast, with early germinate leaves, late defoliation, and luxuriant foliage. In traditional Chinese culture, broken willow branches symbolize parting or retaining, and this appears in many ancient poems. Since ancient times, *S. matsudana* has been a popular green tree species. The dominant species of RGS and SGS was *P. tabulaeformis* var. *mukdensis*, and the sub-dominant species was *Prunus sibirica*. This was because the two species had a high resistance and resilience that allowed them to adapt to the arid and polluted environment. *P. tabulaeformis* var. *mukdensis* has a beautiful tree shape and greens all the year-round. Although it originated in North China, Changchun has more than 100 years of introduction and cultivation, and now it is widely used in all kinds of green space. *P. sibirica* is an important spring flower-viewing tree species in Northeast China and has always been popular. *S. matsudana* was the dominant species both in AGS and PGS, and *U. pumila* was the second dominant tree species in the two spaces. Of the two species, *S. matsudana* can live for more than 200 years, while *U. pumila* has a life span of more than 500 years. Both species are native species with strong ecological services. *P. ussuriensis* occupied an absolute advantage in RGS. *U. pumila* was dominated in OGS, but due to a lack of maintenance and management, many trees were not growing well with some of them were even dying.

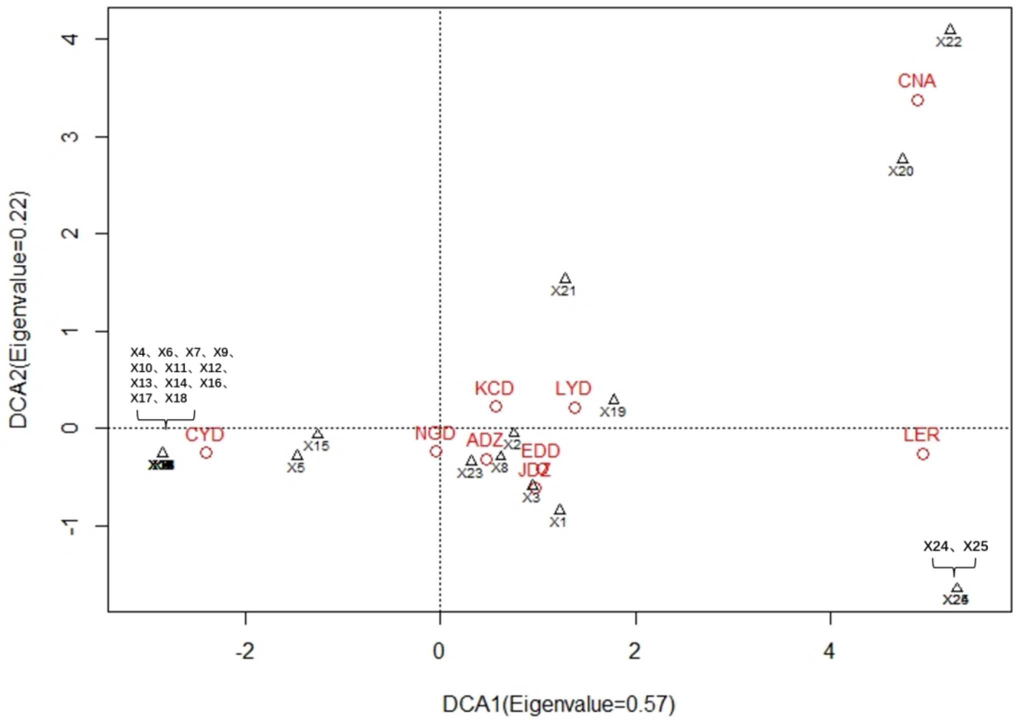

Figure 4. Distribution of Old and Notable Tree species by districts in Changchun. **Note:** The first 2 axes of DCA ordination of districts and Old and Notable Tree species composition. Districts were drawn as circles and species as triangles. Refer to Table S1 for the meaning of districts. X1 denoted *Quercus mongolica*, X2 *Prunus sibirica*, X3 *Ulmus pumila*, X4 *Picea koraiensis*, X5 *Malus baccata*, X6 *Fraxinus mandshurica*, X7 *Maackia amurensis*, X8 *Salix matsudana*, X9 *Crataegus pinnatifida*, X1:0 *Phellodendron amurense*, X11 *Taxus cuspidata*, X12 *Prunus padus*, X13 *Juglans mandshurica*, X14 *Prunus mandshurica*, X15 *Pinus tabulaeformis* var. *mukdensis*, X16 *Tilia amurensis*, X17 *Gleditsia japonica*, X18 *Salix matsudana* var. *matsudana* f. *umbraculifera*, X19 *Salix babylonica*, X20 *Pyrus ussuriensis*, X21 *Acer pictum*, X22 *Abies nephrolepis*, X23 *Morus alba*, X24 *Pinus koraiensis*, and X25 *Juniperus rigida*.

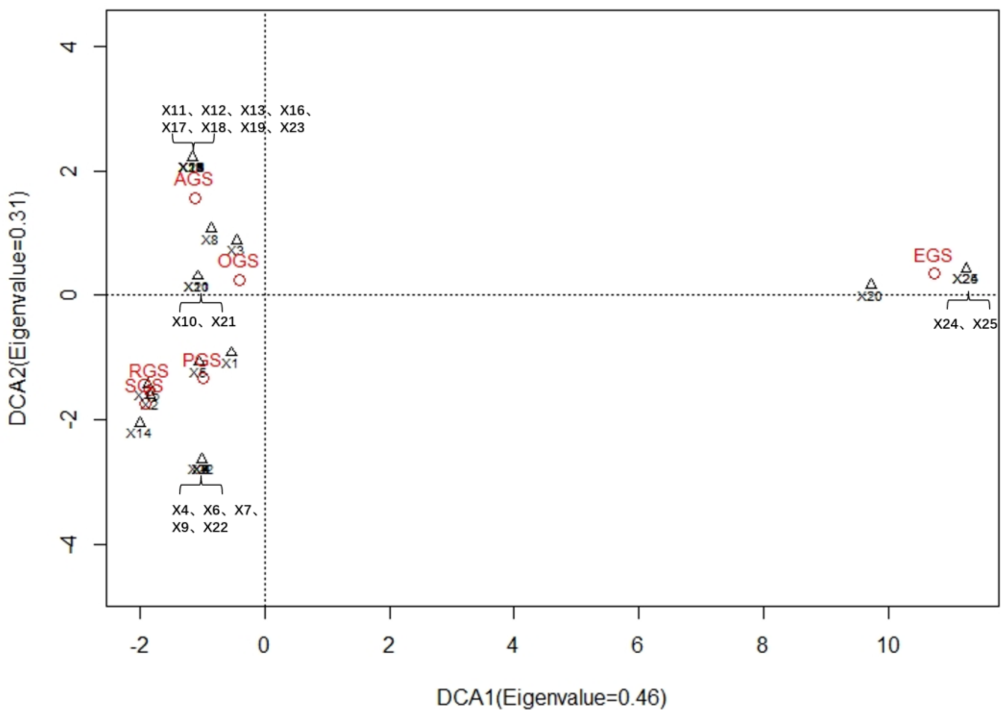

Figure 5. Distribution of Old and Notable Tree species by green space types in Changchun. **Note:** The first 2 axes of DCA ordination of green space types and Old and Notable Tree species composition. Tree green spaces were drawn as circles and species as triangles. Refer to Table S2 for the meaning of green space types. X1 denoted *Quercus mongolica*, X2 *Prunus sibirica*, X3 *Ulmus pumila*, X4 *Picea koraiensis*, X5 *Malus baccata*, X6 *Fraxinus mandshurica*, X7 *Maackia amurensis*, X8 *Salix matsudana*, X9 *Crataegus pinnatifida*, X10 *Phellodendron amurense*, X11 *Taxus cuspidata*, X12 *Prunus padus*, X13 *Juglans mandshurica*, X14 *Prunus mandshurica*, X15 *Pinus tabulaeformis* var. *mukdensis*, X16 *Tilia amurensis*, X17 *Gleditsia japonica*, X18 *Salix matsudana* var. *matsudana* f. *umbraculifera*, X19 *Salix babylonica*, X20 *Pyrus ussuriensis*, X21 *Acer pictum*, X22 *Abies nephrolepis*, X23 *Morus alba*, X24 *Pinus koraiensis*, and X25 *Juniperus rigida*.

3.3. Tree Dimensions and Age

3.3.1. Diameter in Breast Height

The DBH of ONTs in Changchun was between 13.5 and 175.2 cm (Table S4). It was shown in Figure 6 that the number of trees with a DBH from 71 to 90 cm was the largest, accounting for 84.13%. The trees with a DBH > 90 cm accounted for 9.67%, and the main species were fast growing *S. matsudana* and *U. pumila*. The ONTs with a DBH less than 70 cm accounted for 6.19%, and the main species was a conifer species, *Taxus cuspidata*, which grows slowly but has a natural life of more than 1000 years. This species is a first-level nationally protected species in China [5]. Although its DBH was relatively small, it has lived for 195 years in Changchun (Table S4).

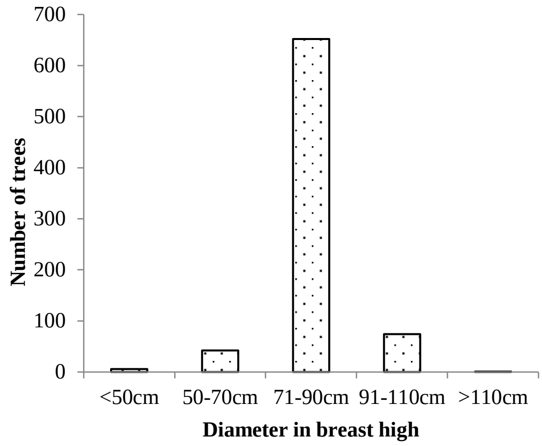

Figure 6. DBH distribution of Old and Notable Trees in Changchun.

The diameter distribution of ONTs changed significantly among different green space types (Figure 7). The number of trees with a DBH of 91 to 110 cm was the largest in PGS, AGS, and OGS, accounting for 42.85%, 45.16%, and 75.00%, respectively. The RGS trees with a DBH of 71 to 90 cm accounted for 99.35%, showing an absolute advantage. Due to the poor environment of RGS and SGS, the DBH was mainly between 50 cm and 70 cm.

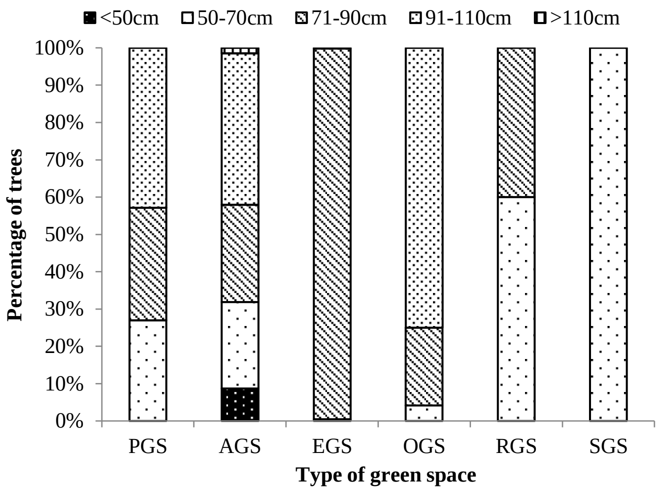

Figure 7. DBH distribution of Old and Notable Trees by green spaces in Changchun. **Note:** Refer to Table S2 for the meaning of the abbreviated green space types.

3.3.2. Tree Height

The height of the ONTs in Changchun was between 6.0 and 31.7 m, and 625 trees were shorter than 10 m (Table S4), accounting for 80.65% of the total trees. There were also significant differences in tree height among the various green types (Figure 8). Tree height from 10 to 15 m accounted for 64.52% in PGS, and the main species was *S. matsudana*, which was grown sparsely near the water, with a plump tree shape and moderate height. Trees in AGS higher than 20 m accounted for 69.57%, and the main species were *U. pumila*, *Juglans mandshurica*, and *Quercus mongolica*. The dominant tree species in RGS was *P. ussuriensis*, but the height was basically less than 10 m. To increase its yield and facilitate picking, the height of *P. ussuriensis* was controlled by pruning. Trees with heights of 16 to 20 m were dominant in OGS (accounting for 75.00%). The tree heights of RGS and SGS were between 10 to 15 m and 16 to 20 m, respectively.

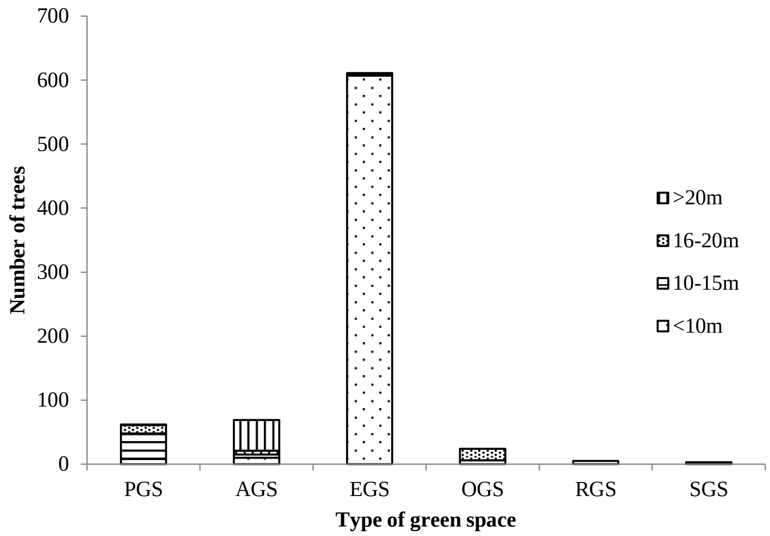

Figure 8. Height distribution of Old and Notable Trees in different green space types. **Note:** Refer to Table S2 for the meaning of the abbreviated green space types.

3.3.3. Tree Crown Cover

Canopy size is an important indicator of a tree's ecological function. The canopy area of the ONTs in Changchun ranged from 7.06 to 400.95 m^2 (Table S4). Trees with a canopy area of 50 to 100 m^2 comprised the largest number of trees (Figure 9), with 659 trees, accounting for 85.0%. These trees were mainly *P. ussuriensis* distributed in the RGS. There were 16 trees with a canopy size less than 50 m^2, accounting for 2.06%, which were mainly coniferous trees, such as *Juniperus rigida*, *T. cuspidata*, and *Picea koraiensis*, growing in the AGS. A canopy size larger than 200 m^2 comprised only six trees, accounting for 0.77%, which included *U. pumila*, *Acer pictum*, and *J. mandshurica* et al. planted in the AGS.

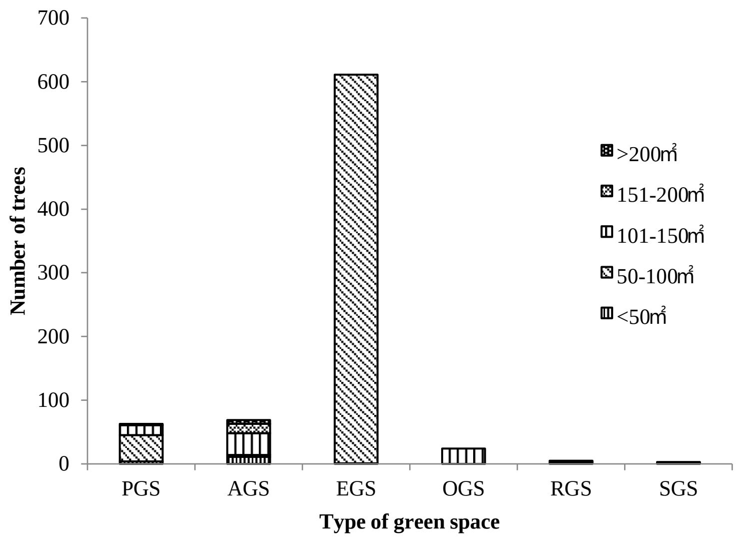

Figure 9. Crown cover distribution of Old and Notable Trees by different green space types in Changchun. **Note:** Refer to Table S2 for the meaning of the abbreviated green space types.

3.3.4. Tree Age

The number of ONTs aged from 201 to 250 years represented the largest amount, with 503 (accounting for 64.90%) *P. ussuriensis* distributed in EGS (Figure 10). A total of 251 trees were in the age range from 100 to 150 years, accounting for 32.39%. The trees older than 300 years were two *U. pumila* growing in the suburbs, aged 310 and 320 years, respectively. The ages of the ONTs in RGS, SGS, PGS, AGS, and OGS were mainly between 100 to 150 years, which was basically consistent with the urban development history.

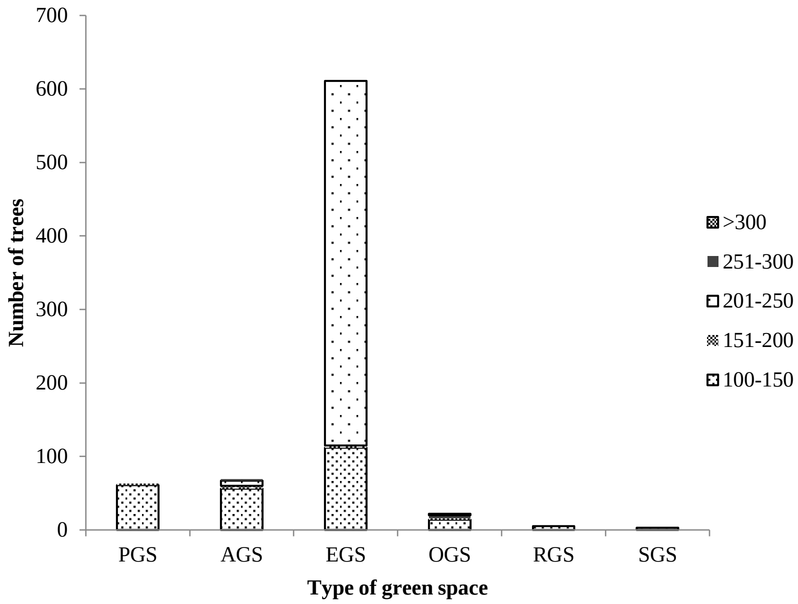

Figure 10. Age distribution of Old and Notable Trees by different green space types in Changchun. **Note:** Refer to Table S2 for the meaning of the abbreviated green space types.

3.3.5. Tree Growth Status

There were significant differences in the growth potentials of ONTs under different environments (Figure 11). PGS and AGS are sound ecological environments, and their normal growth performances accounted for 85.7% and 73.9%, respectively. Weak, heavily weak, and endangered ONTs accounted for 51.7% in OGS, and these trees were mainly in the countryside. The lack of scientific maintenance management measures, especially the timely prevention and control of tree diseases and insect pests, coupled with the inadvertent human destruction, left these trees in poor living conditions. An immediate rejuvenation should be carried out and scientific protection measures should be established in OGS. The growth of ONTs in RGS and SGS was generally average, mainly because the two green space types are greatly affected by traffic pollution and human trampling. In particular, the soil pollution of the road and square was aggravated by snowmelt agents in the winter [39], which increasingly deteriorated the growth environment of the trees. The EGS had been rural land with simple tree management; however, with the change in its land use, people have strengthened the management of ONTs, and the growth condition of the trees has been improved.

The most important ecological services of urban trees consist of reducing the urban heat island intensity and mitigating air pollution [15,40,41]. It was reported that urban cool island intensity (UCI) and a $PM_{2.5}$ concentration were significantly affected by urban tree structures. The tree height and basal area had positive relationships with UCI, either in the summer or autumn [42]. ONTs usually have larger tree heights and basal areas due to their long survival years. In this study, except for *P. ussuriensis* and *Gleditsia japonica*, the ONTs in Changchun were higher than 10.7 m (Table S4), which helped to contribute to the UCI effect. Moreover, 97% of ONTs had a mean basal area larger than 0.35 m^2 (Table S4), which indicated their capability for mitigating the urban heat island phenomenon of ONTs. In addition, the $PM_{2.5}$ concentration index would decrease as the tree DBH increased in the daytime [43]. Our results demonstrated that besides *Fraxinus mandshurica* and *T. cuspidata*, the other 24 species all had a mean DBH larger than 51.2 cm. Therefore, ONTs play a more important role in reducing $PM_{2.5}$ concentration than the small-sized urban trees.

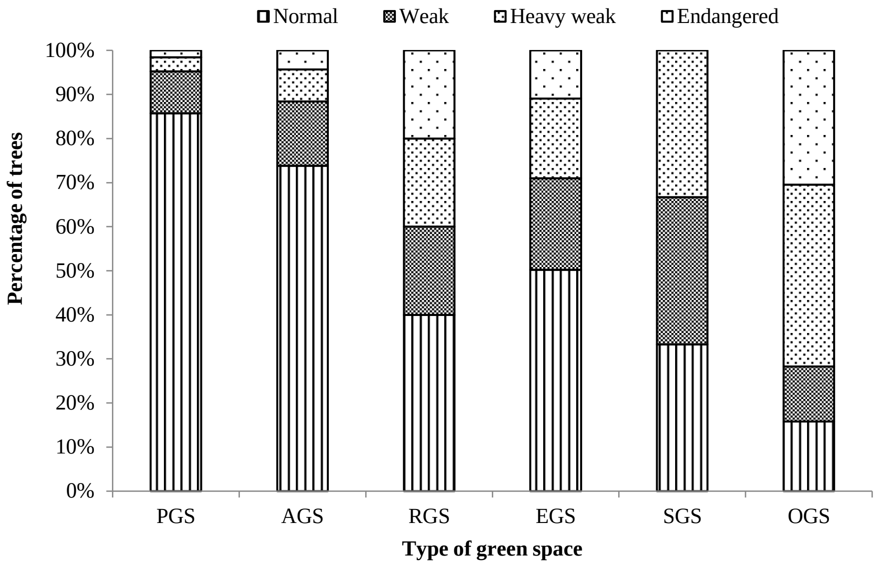

Figure 11. The growth status of Old and Notable Trees in Changchun. **Note:** Refer to Table S2 for the meaning of the abbreviated green space types.

3.4. Comparison of ONTs in Three Adjacent Cities of Changchun, Shenyang, and Harbin in Northeast China

3.4.1. Species Diversity of ONTs in the Three Cities

Changchun, Shenyang, and Harbin are three of the most important industrial cities in Northeast China, and they are the capitals of Jilin, Liaoning, and Heilongjiang Provinces, respectively. There were obvious differences in the species and quantities of ONTs in the three cities (Table 2, Figure 12). The number and species of ONTs in Shenyang (2979 trees of 28 species) were significantly higher than those in the other two cities (Figure 12). The number of species of ONTs in Changchun (25 species) were higher than in Harbin (18 species), (Figure 12b), but the number of trees (775 trees) was lower than in Harbin (1075 trees), (Figure 12a). The built-up areas of Changchun, Harbin, and Shenyang were 543.2 km^2, 445.8 km^2, and 563.0 km^2 [31,44,45], respectively. Therefore, it was concluded that the densities of the ONTs in Changchun, Harbin, and Shenyang were 1.4, 2.4, and 5.3 trees/km^2, respectively. Shenyang was built in the early Qing Dynasty and is the birthplace of the Qing Dynasty [45]. It has a history of more than 400 years. Changchun and Harbin were both built in the late Qing Dynasty and have a history of more than 100 years [31,44]. The Russian Far East Railway, built in the late 19th century, greatly promoted the development of the two cities, and Harbin has become an international commercial port since the beginning of the 20th century. This demonstrates that the number of ONTs was closely related to the history of urban construction, and that the opening of the city also has a positive effect on the protection of ONTs, which is consistent with the results of Zhang et al. regarding Macao, Hong Kong, and Guangzhou [26].

Table 2. Comparison of Old and Notable Trees in Northeast China, namely Changchun (CC), Shenyang (SY), and Harbin (HB), with reference to the number of trees and species, species diversity (H′), evenness (J), and dominant species.

City	Key Attribute	No. of Trees	No. of Species	H′	J	Dominant Species	Refs
CC	Overall [a]	775	25	0.97	0.3	*Pyrus ussuriensis*	This Study
	Mean [a,b]	86	5	0.96	0.66		[31]
	Max. [a]	497	18	2.04	0.96		
	(District)	(CNA)	(CYD)	(CYD)	(JDZ)		
	Min. [a]	3	2	0.03	0.03		
	(District)	(ADZ)	(ADZ)	(ADZ)	(ADZ)		
SY	Overall [a]	2979	28	0.44	0.13	*Pinus tabulaeformis*	
	Mean [a,b]	331	5	0.75	0.47		
	Max. [a]	2152	12	2.1	0.95		[45,46] [c]
	(District)	(HGD)	(HGD)	(HPD)	(SBZ)		
	Min. [a]	4	2	0.11	0.05		
	(District)	(SBZ)	(QPZ)	(HGD)	(HGD)		
HB	Overall [a]	1075	18	0.46	0.16	*Ulmus pumila*	[41,47]
	Mean [a,b]	134	6	0.65	0.41		
	Max. [a]	398	9	1.73	0.89		
	(District)	(NGD)	(ACD)	(ACD)	(ACD)		
	Min. [a]	17	3	0.13	0.12		
	(District)	(ACD)	(SBD)	(SBD)	(SBD)		

Notes: In Shenyang (SY): HGD denotes Huanggu District; HPD denotes Heping District; SBZ denotes Northern Shenyang New Zone; QPD denotes Qipanshan Development Zone. In Harbin (HB): NGD denotes Nangang District; ACD denotes Acheng District; SBD denotes Songbei District. [a] 'Overall' indicates the values of the whole city; 'Mean' indicates the mean values over the number of subdivided districts; 'Max' and 'Min' indicate the maximum and minimum values, respectively, and the district holding the record. [b] The analysis includes 9 districts in Changchun, 9 districts in Shenyang and 8 districts in Harbin. [c] The book was published in 2008, and we adjusted the data by consulting with Bureau of Forestry and Landscaping of Shenyang.

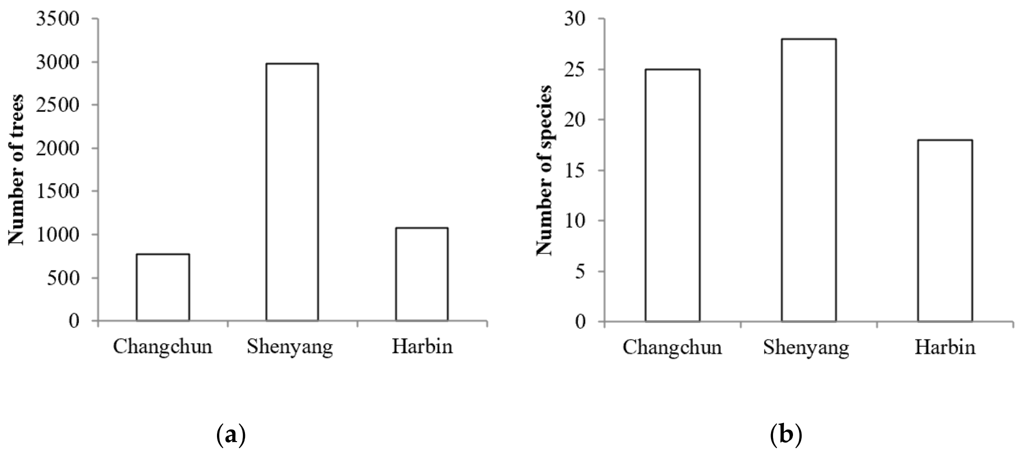

Figure 12. Comparison of Old and Notable Trees among three cities in Northeast China with reference to: (**a**) number of trees; (**b**) number of species.

The annual average temperature of Shenyang (41°11′–43°02′ N) was 8.4 °C with annual precipitation of 600–800 mm [45]. In Harbin (44°04′–46°40′ N), the annual average temperature was 4.2 °C, and the annual precipitation was 569.1 mm [44]. The climatic conditions of Shenyang were obviously better than Changchun and Harbin, so the species of ONTs were richer than the other two cities. Some warm temperate species such as *Sophora japonica*, *Cerasus yedoensis*, *Ailanthus altissima*, and *Celtis Koraiensis* (Table S5) were present in Shenyang. Due to the long winter and cold climate, Harbin has the fewest ONT species, and all the ONTs were local trees with strong cold resistance, such as *U. pumila*, *Populus nigra* var. *italica*, *J. mandshurica*, *Populus simonii*, and *Phellodendron amurense* et al. (Table S6).

P. ussuriensis was the dominant ONT species in Changchun (Table 1) for the pear orchards preserved in the suburbs. Shenyang was the cradle and ruling center of the Qing Dynasty, and it has many royal palaces and tombs that were built in the early 17th century. *Pinus. tabulaeformis* is a traditional fengshui tree species in China which is popular in royal gardens. The human beliefs and spiritual ballast of fengshui trees always determine the ONTs' existence [13,48–50]. *P. tabulaeformis* grows vigorously and is green all year round with a life span of more than 500 years. Therefore, *P. Tabulaeformis* had an absolute advantage over the other ONTs in Shenyang, and its IV reached 94.50% (Table S5). *U. pumila* has strong cold and drought resistance, which enables it to grow and develop normally in the urban environment with strong human disturbance [47]. At the same time, it is also a broadleaf species with the longest life span in this region. These excellent characteristics grant *U. pumila* an absolute advantage in Northeast China, and its IV ranked the first, second, and third place in Harbin, Shenyang, and Changchun, respectively (Tables S4–S6).

The number and species of ONTs in different urban areas vary greatly (Table 2), and the distribution of ONTs showed an obvious spatial heterogeneity. HGD is the administrative, scientific, technological, cultural, and educational center of Shenyang. The Qing Zhaoling Mausoleum built in the early Qing Dynasty is also located in this area. Its citizens have a strong awareness of tree protection, so the species and quantity of ONTs were the largest, with 2152 trees of 12 species accounting for 72.24% of ONTs in Shenyang. SBZ was developed from agricultural land in 2006, and there were only four ONTs in this district [46] because of the villagers' poor ecology protection awareness. NGD in Harbin has a long history of construction. In the early years, it was mainly inhabited by foreign nationals. Then, it became a concentrated area for universities and scientific research institutes after the founding of the People's Republic of China. The excellent quality of its citizens and environment ensure that its ONTs are well protected. The number of ONTs (398 trees) in this area was the highest in Harbin. ACD used to be a village, and due to the weakness of the protection planning of its ONTs, many precious trees were destroyed in the process of urban development, and only 17 ONTs remained [47].

To further study the diversity differences of ONTs in the three neighboring cities, LSD (Least significant difference) statistical analysis was conducted on the species diversity index and evenness index in different urban areas of the three cities (Table S7). However, the results showed that there were no significant differences in the species diversity index and evenness index among the three cities ($p > 0.05$).

SIMPER analysis of the ONTs in Changchun, Shenyang, and Harbin was carried out based on the IVs of the tree species. The results demonstrated that the similarity of ONTs in the three cities was very low. The similarity between Shenyang and Harbin was the largest, but was only 32.94%, while the similarity between Changchun and Shenyang, and Changchun and Harbin was 18.53% and 18.17%, respectively. Due to the differences in the environmental conditions and history, there were some endemic species in the three cities. In Changchun the species were *Abies nephrolepis*, *P. koraiensis*, *J. rigida*, *T. cuspidata*, *Prunus mandshurica*, *Crataegus pinnatifida*, *A. pictum* and *Salix. matsudana* var. *matsudana* f. *umbraculifera*, Shenyang were *Ginkgo biloba*, *Pinus banksiana*, *Juniperus chinensis*, *Platycladus orientalis*, *Taxus cuspidata* var. *nana*, *Quercus acutissima*, *Quercus liaotungensis*, *Salix matsudana* f. *pendula*, *C. koraiensis*, *Celtis bungeana*, *C. yedoensis*, *S. japonica*, *Euonymus bungeanus*, *Fraxinus americana*, and *A. altissima*; and in Harbin were *P. nigra* var. *italica*, *P. simonii*, and *Larix gmelinii* (Tables S4–S6).

3.4.2. The DBH, Tree Height, and Age Distribution of ONTs in Three Cities

The DBH distribution of the ONTs in Changchun, Shenyang, and Harbin showed the same trend (Figure 13). The number of trees with a DBH between 61 to 90 cm was the largest, accounting for 78.06%, 94.50%, and 74.70% in Changchun, Shenyang, and Harbin, respectively. There was few trees with a DBH less than 30 cm and larger than 150 cm. In the three cities, ONTs with a DBH smaller than 30 cm were mainly shrubs and slow-growing coniferous trees, while those with a DBH larger than 150 cm were Populus and Salix trees, which grow fast with a short life span, and few individuals reach more than 100 years.

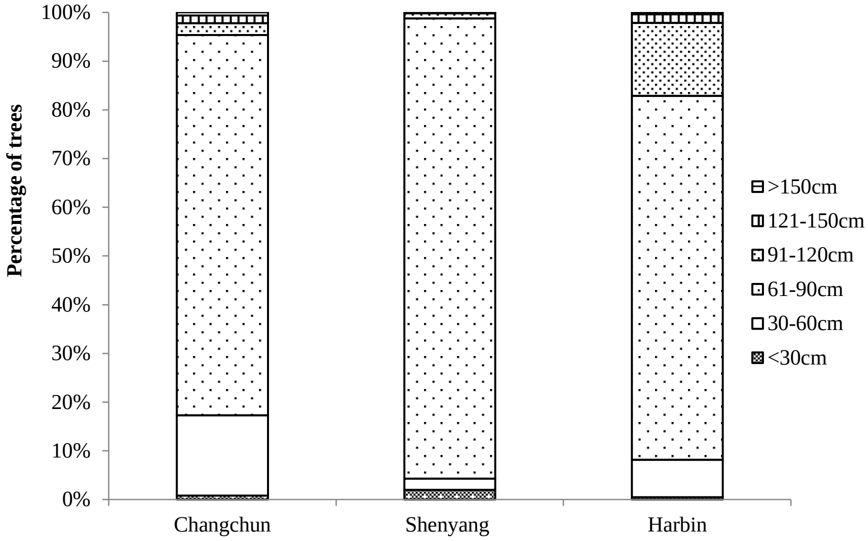

Figure 13. Comparison of DBH of Old and Notable Trees among three cities in Northeast China.

The tree height distributions of the ONTs in the three cities were obviously different (Figure 14). A tree height less than 10 m in Changchun accounted for 80.65%, a height from 10 to 15 m in Shenyang account for 74.69%, and 92.46% trees in Harbin were 16 to 20 m. The distribution of tree height was mainly determined by the planting purpose and the characteristics of the dominant tree species in each city. *P. ussuriensis* was the dominant ONT species in Changchun, and its tree height was regulated through pruning by planters to improve the yield and facilitate picking. *P. tabulaeformis* occupied an absolutely dominant position in Shenyang, and most of these trees were in the royal gardens of the Qing Dynasty. To form a beautiful tree shape, *P. tabulaeformis* was generally planted sparsely, which contributed to its tree height. The dominant tree species in Harbin was *U. pumila*, which was naturally tall and luxuriant, with a natural growth height higher than 20 m.

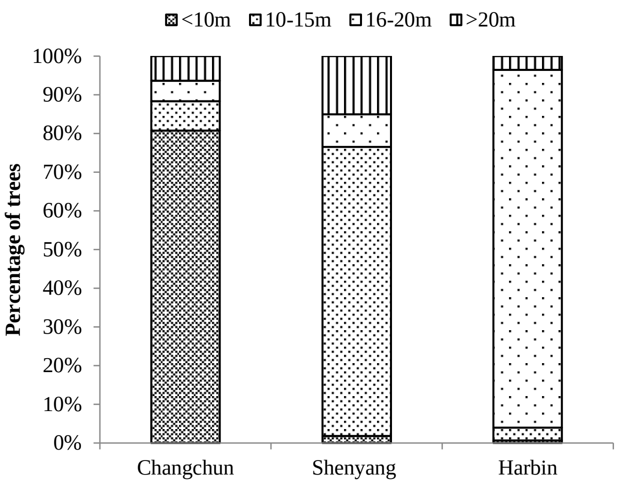

Figure 14. Comparison of height of Old and Notable Trees among three cities in Northeast China.

Due to the different histories of the three cities, the tree ages of the ONTs were also significantly different (Figure 15). Shenyang has the longest history, and the average age of its ONTs was significantly higher than that of Changchun and Harbin. There were 2458 first grade ONTs (more than 300 years old) in Shenyang, accounting for 82.51% of the total number (Table S5). However, only two and three first-grade ONTs appeared in Changchun and Harbin, respectively (Tables S4 and S6). The ONT ages between 200 and 300 years were dominant (79.48%) in Changchun, and from 100 to 200 years were dominant (82.32%) in Harbin.

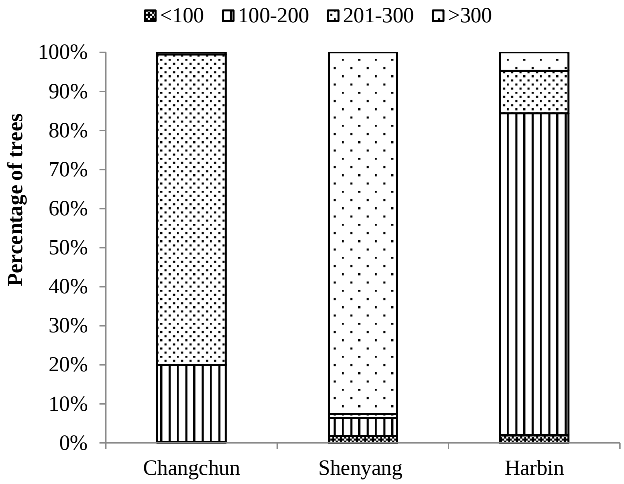

Figure 15. Comparison of age of Old and Notable Trees among three cities in Northeast China.

4. Conclusions and Implications

ONTs lived for more than one hundred years have strong vitality and adaptability. They are not only an important part of urban landscape, but also a symbol of an ecological city and a witness to urban changes. Notably, old trees tended to have relatively stabler growth rates than young trees, showing their remarkable resistance to climate warming [51]. The presence of ONTs can affect the climate; when they die, the carbon they have stored is released into the atmosphere and contributes to global warming [52]. In addition, the growth characteristics of ONTs can also reflect the urban environmental changes over a long period. For example, there is a certain correspondence between tree rings and climate. The years with extremely narrow tree rings reflect extreme events, such as drought and insect infestation [53], which can supplement the urban information of previous years. Therefore, the protection for ONTs is crucial for future urban sustainable development.

This study fully investigated all the ONTs in Changchun and analyzed the interactions between trees' appearance and urban history. It was concluded that tree-habitat conditions and the human initiatives towards trees' protection were the main factors determining the ONTs' existence and growth status. The good site conditions at EGS, PGS, and AGS were the decisive factors determining the ONTs' growth status and even their survival times. The comparison of ONTs in Shenyang, Changchun, and Harbin indicated that the species decreased with the increase of latitude, which illustrated that the distribution of ONTs was also affected by climate conditions. However, due to the influence of human interference, the number of ONTs did not change monotonously with the latitude. The DBH, height, and age of ONTs in different cities were influenced by the history and development of the cities, the planting purposes, and the human preferences.

With the intensification of urbanization around the world, the survival pressure on ONTs is intensifying. For the better protection of these precious resources, several recommendations should be adopted in future management:

(1) Adequate protection measures and rules towards the maintenance of ONTs must be established. However, these regulations usually receive limited attention. Nevertheless, ONTs can be connected to human minds for their historical characters; therefore, it is a better idea to set up ONTs as a conservation flagship for awakening the residents' ecological protection awareness, and to actively guide and encourage them to consciously cultivate and protect ONTs.

(2) Necessary conservation measures should be taken in a timely manner for ONTs in weak growth conditions, such as the improvement of soil, the application of fertilizer, the expansion of the tree pool, and the pruning of branches and leaves. For natural disasters, contingency plans and measures should be formulated in time. In addition, as ONTs are consistently lost worldwide, it is necessary to establish a dynamic monitoring platform to observe their changes regularly.

(3) The use of snowmelt agents must be strictly controlled. The snow clearing methods should be artificial and mechanical, and supplemented by snowmelt agents. The type, dosage, and concentration of snowmelt agents should be strictly controlled. Furthermore, a protection zone should be set up around each ONT. Non-chlorinated environment-friendly snowmelt agents (such as organic or inorganic amines and alcohols) are recommended for use near the ONT zones. In addition, advanced snow removal methods, such as the use of thermal energy, should be vigorously advocated.

(4) The development of ONT tourism should be strengthened. ONTs can be used to design tourist routes and carry out activities with different themes; for example, culturally themed tourism concerning ONTs alongside famous mountains and gardens, myths and legends, anecdotes of celebrities, etc.; ecologically themed tourism of "Green, Ancient, Vigorous, Simple and Strange" ONTs; and activities that study their growth rates/restrictions and their relationship with the surrounding environment. In addition, ONTs' use as the main landscape together with the basic elements of garden landscape, including terrain, water, rocks, structures, landscape facilities, plants, and garden articles, as well as the texture, shape, color, and line, could facilitate a landscape of artistic conception that would increase human attention towards ONTs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14137937/s1, Table S1: The main districts in Changchun: Land area, green cover, population and development year; Table S2: The six tree-habitats which accommodate Old and Notable Trees in Changchun; Table S3: Classification for growth potential of Old and Notable Trees; Table S4: Old and Notable Tree species list of Changchun city; Table S5: Old and Notable Tree species list of Shenyang city; Table S6: Old and Notable Tree species list of Harbin city; Table S7: LSD analysis of diversity index and evenness index of Old and Notable Trees in Changchun, Shenyang and Harbin.

Author Contributions: Y.Y., G.B. and D.Z. lead to collect the data. Field data were analyzed by Y.Y., D.Z. and C.Z. The manuscript was written by Y.Y. and C.Z. The article was revised by D.Z. and G.B. All authors have read and agreed to the published version of the manuscript.

Funding: The research article was supported by Science and Technology Project of the Bureau of Forestry and Landscaping of Changchun (2018JBH27L19), "The 13th Five-year Plan" Science and Technology Project of the Education Department of Jilin Province (JJKH20200560KJ), the Scientific Research Cultivation Project of Changchun University (ZKC202005; ZKQ201913), and the "Climbing" Program of Changchun University (ZKP202015).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank Bureau of Forestry and Landscaping of Changchun, and the students at Changchun University who helped to conduct the field survey.

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

References

1. Qiu, Z.; Feng, Z.-K.; Wang, M.; Li, Z.; Lu, C. Application of UAV Photogrammetric System for Monitoring Ancient Tree Communities in Beijing. *Forests* **2018**, *9*, 735. [CrossRef]
2. Xie, C.; Yu, X.; Liu, D.; Fang, Y. Modelling Suitable Habitat and Ecological Characteristics of Old Trees Using DIVA-GIS in Anhui Province, China. *Pol. J. Environ. Stud.* **2020**, *29*, 1931–1943. [CrossRef]

3. Caron, T.M.F.; Chuma, V.; Sandi, A.A.; Norris, D. Big trees drive forest structure patterns across a lowland Amazon regrowth gradient. *Sci. Rep.* **2021**, *11*, 3380. [CrossRef] [PubMed]
4. Thirumurugan, V.; Prabakaran, N.; Sreedharan Nair, V.; Ramesh, C. Ecological importance of two large heritage trees in Moyar River valley, southern India. *J. Threat. Taxa* **2021**, *13*, 17587–17591. [CrossRef]
5. *LY/T 2738-2016*; Technical Regulation for Surveying of Old and Notable Trees. National Forestry Administration: Beijing, China, 2016.
6. Lindenmayer, D.B.; Laurance, W.F.; Franklin, J.F. Global Decline in Large Old Trees. *Science* **2012**, *338*, 1305–1306. [CrossRef] [PubMed]
7. Hartel, T.; Hanspach, J.; Moga, C.I.; Holban, L.; Szapanyos, A.; Tamas, R.; Hovath, C.; Reti, K.O. Abundance of large old trees in wood-pastures of Transylvania (Romania). *Sci. Total Environ.* **2018**, *613–614*, 263–270. [CrossRef] [PubMed]
8. Bordin, K.M.; Esquivel-Muelbert, A.; Bergamin, R.S.; Klipel, J.; Picolotto, R.C.; Frangipani, M.A.; Zanini, K.J.; Cianciaruso, M.V.; Jarenkow, J.A.; Jurinitz, C.F.; et al. Climate and large-sized trees, but not diversity, drive above-ground biomass in subtropical forests. *For. Ecol. Manag.* **2021**, *490*, 119126. [CrossRef]
9. Clark, D.B.; Ferraz, A.; Clark, D.A.; Kellner, J.R.; Letcher, S.G.; Saatchi, S. Diversity, distribution and dynamics of large trees across an old-growth lowland tropical rain forest landscape. *PLoS ONE* **2019**, *14*, e0224896. [CrossRef]
10. Poulsen, J.R.; Medjibe, V.P.; White, L.J.T.; Miao, Z.; Banak-Ngok, L.; Beirne, C.; Clark, C.J.; Cuni-Sanchez, A.; Disney, M.; Doucet, J.L.; et al. Old growth Afrotropical forests critical for maintaining forest carbon. *Glob. Ecol. Biogeogr.* **2020**, *29*, 1785–1798. [CrossRef]
11. Liu, J.; Lindenmayer, D.B.; Yang, W.; Ren, Y.; Campbell, M.J.; Wu, C.; Luo, Y.; Zhong, L.; Yu, M. Diversity and density patterns of large old trees in China. *Sci. Total Environ.* **2019**, *655*, 255–262. [CrossRef]
12. Lindenmayer, D.B. Conserving large old trees as small natural features. *Biol. Conserv.* **2017**, *211*, 51–59. [CrossRef]
13. Chen, W.Y.; Hua, J. Heterogeneity in resident perceptions of a bio-cultural heritage in Hong Kong: A latent class factor analysis. *Ecosyst. Serv.* **2017**, *24*, 170–179. [CrossRef]
14. Huang, L.; Tian, L.; Zhou, L.; Jin, C.; Qian, S.; Jim, C.Y.; Lin, D.; Zhao, L.; Minor, J.; Coggins, C.; et al. Local cultural beliefs and practices promote conservation of large old trees in an ethnic minority region in southwestern China. *Urban For. Urban Green.* **2020**, *49*, 126584. [CrossRef]
15. Asanok, L.; Kamyo, T.; Norsaengsri, M.; Yotapakdee, T.; Navakam, S. Assessment of the Diversity of Large Tree Species in Rapidly Urbanizing Areas along the Chao Phraya River Rim, Central Thailand. *Sustainability* **2021**, *13*, 10342. [CrossRef]
16. Lai, P.Y.; Jim, C.Y.; Tang, G.D.; Hong, W.J.; Zhang, H. Spatial differentiation of heritage trees in the rapidly-urbanizing city of Shenzhen, China. *Landsc. Urban Plan.* **2019**, *181*, 148–156. [CrossRef]
17. Lindenmayer, D.B.; Blanchard, W.; Blair, D.; McBurney, L.; Banks, S.C. Environmental and human drivers influencing large old tree abundance in Australian wet forests. *For. Ecol. Manag.* **2016**, *372*, 226–235. [CrossRef]
18. Vandekerkhove, K.; Vanhellemont, M.; Vrška, T.; Meyer, P.; Tabaku, V.; Thomaes, A.; Leyman, A.; De Keersmaeker, L.; Verheyen, K. Very large trees in a lowland old-growth beech (*Fagus sylvatica* L.) forest: Density, size, growth and spatial patterns in comparison to reference sites in Europe. *For. Ecol. Manag.* **2018**, *417*, 1–17. [CrossRef]
19. Ali, A.; Wang, L.-Q. Big-sized trees and forest functioning: Current knowledge and future perspectives. *Ecol. Indic.* **2021**, *127*, 107760. [CrossRef]
20. Lindenmayer, D.B.; Laurance, W.F. The ecology, distribution, conservation and management of large old trees. *Biol. Rev. Camb. Philos. Soc.* **2017**, *92*, 1434–1458. [CrossRef]
21. Wan, J.-Z.; Li, Q.-F.; Wei, G.-L.; Yin, G.-J.; Wei, D.-X.; Song, Z.-M.; Wang, C.-J. The effects of the human footprint and soil properties on the habitat suitability of large old trees in alpine urban and periurban areas. *Urban For. Urban Green.* **2020**, *47*, 126520. [CrossRef]
22. Vechiu, E.; Dinca, L.; Breabăn, I.G. Old Forests from Dobrogea's Plateau. *Present Environ. Sustain. Dev.* **2021**, *15*, 171–178. [CrossRef]
23. Xie, C.; Dong, W.; Liu, D. Species diversity and distribution pattern of old trees in Wuzhong district, Suzhou city. *Pak. J. Bot.* **2020**, *52*, 1335–1343. [CrossRef]
24. Jim, C.Y. Monitoring the performance and decline of heritage trees in urban Hong Kong. *J. Environ. Manag.* **2005**, *74*, 161–172. [CrossRef] [PubMed]
25. Liu, J.; Jiang, R.-Y.; Zhang, G.-F. Number and distribution of large old ginkgos in east China: Implications for regional conservation. *Nat. Conserv.* **2020**, *42*, 71–87. [CrossRef]
26. Zhang, H.; Lai, P.Y.; Jim, C.Y. Species diversity and spatial pattern of old and precious trees in Macau. *Landsc. Urban Plan.* **2017**, *162*, 56–67. [CrossRef]
27. Lindenmayer, D.B.; Laurance, W.F. The Unique Challenges of Conserving Large Old Trees. *Trends Ecol. Evol.* **2016**, *31*, 416–418. [CrossRef]
28. Yichao, Y. Japanese Construction of Manchukuo—Take Changchun Urban Planning as an Example. *Urban Creat.* **2018**, *169*, 159–160.
29. Zhou, G.; Zhang, J.; Li, C.; Liu, Y. Spatial Pattern of Functional Urban Land Conversion and Expansion under Rapid Urbanization: A Case Study of Changchun, China. *Land* **2022**, *11*, 119. [CrossRef]
30. Statistic Bureau of Jilin. *Jilin Statistical Yearbook*; Statistic Bureau of Jilin: Changchun, China, 2021.

31. Changchun Bureau of Statistics. *Changchun Statistical Yearbook*; Changchun Bureau of Statistics: Changchun, China, 2021.
32. Jim, C.Y. Spatial differentiation and landscape-ecological assessment of heritage trees in urban Guangzhou (China). *Landsc. Urban Plan.* **2004**, *69*, 51–68. [CrossRef]
33. *CJJ/T85-2017*; Standard for Classification of Urban Green Space. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China, 2017.
34. Jim, C.Y.; Zhang, H. Species diversity and spatial differentiation of old-valuable trees in urban Hong Kong. *Urban For. Urban Green.* **2013**, *12*, 171–182. [CrossRef]
35. Shannon, E.C.; Weaver, W. *The Mathematical Theory of Communication*; University of Illinois Press: Urbana, IL, USA, 1963.
36. Magurran, A.E. *Ecological Diversity and its Measurement*; Princeton University Press: Princeton, NJ, USA, 1988.
37. Pielou, E.C.J. The measurement of diversity in different types of biological collections. *J. Theor. Biol.* **1967**, *13*, 131–144. [CrossRef]
38. Mueller-Dombois, D.; Ellenberg, H. *Aims and Methods of Vegetation Ecology*; Wiley: New York, NY, USA, 1974.
39. Yu, S. Study on the current situation of snow melting agent and countermeasures to reduce its harm in Changchun city. *Resour. Conserv. Environ. Prot.* **2015**, *11*, 179. [CrossRef]
40. Wang, C.; Ren, Z.; Dong, Y.; Zhang, P.; Guo, Y.; Wang, W.; Bao, G. Efficient cooling of cities at global scale using urban green space to mitigate urban heat island effects in different climatic regions. *Urban For. Urban Green.* **2022**, *74*, 127635. [CrossRef]
41. Wu, J.; Wang, Y.; Qiu, S.; Peng, J. Using the modified i-Tree Eco model to quantify air pollution removal by urban vegetation. *Sci. Total Environ.* **2019**, *688*, 673–683. [CrossRef] [PubMed]
42. Ren, Z.; He, X.; Pu, R.; Zheng, H. The impact of urban forest structure and its spatial location on urban cool island intensity. *Urban Ecosyst.* **2018**, *21*, 863–874. [CrossRef]
43. Liu, X.; Yu, X.; Zhang, Z. PM2.5 Concentration Differences between Various Forest Types and Its Correlation with Forest Structure. *Atmosphere* **2015**, *6*, 1801–1815. [CrossRef]
44. *Harbin Statistical Yearbook*; Harbin Municipal People's Government: Harbin, China, 2021.
45. *Shenyang Statistical Yearbook*; Shenyang Statistics Bureau: Shenyang, China, 2021.
46. *Shenyang Old and Valuable Trees*; Liaoning Science and Technology Press: Shenyang, China, 2008.
47. Wang, N.Y.M.; Wang, Q.; Shi, B.; Yan, Y. Current Situation and Analysis of Ancient and Famous Trees in Harbin. *J. Zhejiang For. Sci. Technol.* **2018**, *38*, 77–84. [CrossRef]
48. Huang, L.; Jin, C.; Zhen, M.; Zhou, L.; Qian, S.; Jim, C.Y.; Lin, D.; Zhao, L.; Minor, J.; Coggins, C.; et al. Biogeographic and anthropogenic factors shaping the distribution and species assemblage of heritage trees in China. *Urban For. Urban Green.* **2020**, *50*, 126652. [CrossRef]
49. Frascaroli, F.; Bhagwat, S.; Guarino, R.; Chiarucci, A.; Schmid, B. Shrines in Central Italy conserve plant diversity and large trees. *Ambio* **2016**, *45*, 468–479. [CrossRef]
50. Thaiutsa, B.; Puangchit, L.; Kjelgren, R.; Arunpraparut, W. Urban green space, street tree and heritage large tree assessment in Bangkok, Thailand. *Urban For. Urban Green.* **2008**, *7*, 219–229. [CrossRef]
51. Colangelo, M.; Camarero, J.J.; Gazol, A.; Piovesan, G.; Borghetti, M.; Baliva, M.; Gentilesca, T.; Rita, A.; Schettino, A.; Ripullone, F. Mediterranean old-growth forests exhibit resistance to climate warming. *Sci. Total Environ.* **2021**, *801*, 149684. [CrossRef] [PubMed]
52. Limin, A.; Slik, F.; Sukri, R.S.; Chen, S.B.; Ahmad, J.A. Large tree species composition, not growth rates, is affected by topography in a Bornean tropical forest. *Biotropica* **2021**, *53*, 1290–1300. [CrossRef]
53. Li, Y.; Fang, K.; Bai, M.; Cao, X.; Dong, Z.; Tang, W.; Mei, Z. Ecological resilience of ancient *Pinus massoniana* trees to climate change and insect infestation in southeastern Fujian, China. *Chin. J. Appl. Ecol.* **2021**, *32*, 3539–3547. [CrossRef]