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Species Diversity and Distribution Pattern of Heritage Trees in the Rapidly-Urbanizing Province of Jiangsu, China

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Abstract: Heritage trees have important ecological, historical, and landscape values in cities. Rapid urbanization may cause dramatic change of ecosystem functions of cities, thereby inevitably affecting the growth performance of ancient trees. However, few studies have explored their species diversity and spatial differentiation on the medium scale in the scenario of urbanization in China. Here, we took Jiangsu Province in China, with developed economy in recent decades, as a typical case. Based on the provincial forest inventory data, we addressed the abundance, species richness, tree density, and species diversity of ancient trees in 13 cities, and their tree habitat, growth status, and tree age, as well. Then, we compared the spatial differentiation of tree attributes by 13 districts and nine tree habitats. We also applied detrended correspondence analysis (DCA) and redundancy analysis (RDA) to determine the leading factor influencing their distribution pattern. The 7678 heritage trees in Jiangsu belonged to 215 species. More than half of the trees were native with domination by *Ginkgo biloba*. Villages and farmlands accommodated the most heritage trees while parks and gardens harbored the most species. This indicates that sparsely-populated rural community and scenic areas with open space are conducive to accommodating more urban heritage trees. The tier 3 heritage trees (100–299 years) accounted for about 80% of the total. Overall, most ancient trees in Jiangsu grew well. The species diversity index (H) of 13 cities was between 1.98 and 3.39. The H value among the 13 cities was largely affected by elevation range shift, while the tree density by GDP per capita. DCA showed that the ratio of unique species was >40%, and that dominant species presented little habitat preference. Therefore, species diversity among different cities are affected by climate and topography, as well as human factors. With the accelerating urbanization process, tree habitat, cultural tradition, and urban history should be taken into consideration for management and conservation of heritage trees in the future.

Keywords: old–valuable tree; spatial differentiation; tree habitat; unique species; urbanization

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1. Introduction

Heritage trees are essential components of urban ecosystems because they can offer direct and indirect ecosystem services [1–3]. As large trees, they, per se, are part of floristic composition in a city, playing an important role in urban forests. Simultaneously, they can provide food, shelter, and living space or create distinct habitats for other plants and animals, especially for some birds and insects [4–6].

Heritage trees, at least 100 years old, tend to be large in size: tree height, crown spread, and/or trunk girth [7]. Therefore, they can form the urban landscape, and create an amenity urban environment for human beings [8,9]. For example, ancient trees can provide shade for pedestrians through spreading branches and thick foliage and help them keep from overheating by transpiration during the summer. This is of high importance in densely populated areas of a city. Most ancient trees also have a variety of ornamental value, such as thick trunks, fragrant flowers and fruit, or colorful leaves in different seasons [10]. Take *Cinnamomum camphora* as an example; it contains a special aroma and volatile oil

when in blossom. Another example is *Ginkgo biloba*, whose green leaves in summer turn into golden yellow in autumn. In addition, its seeds are edible. Therefore, ancient trees in tandem with urban architecture can become a unique landscape unit or a beautiful landmark of the city.

Besides, some ancient urban trees can be seen as a witness of city's vicissitudes or regarded as mascots on which people place their hope and feeling [11,12].

Currently, the studies concerning urban ancient trees cover a variety of themes, such as field investigation [13–15], spatial distribution [7,16], rejuvenation and pest control [17–19], and protection legislation [20–22], as well as the aesthetic and spiritual aspects of ancient trees [23,24]. Among them, most studies have focused on species diversity and spatial differentiation [7,25]. According to different dimensions, the current studies can be roughly divided into three major categories. On a large scale (i.e., national or international level), it seems reasonable to determine the factors contributing to the distribution pattern because of a wide variation of climate [26]. However, due to required data being hard to obtain, such studies are likely conducted using indirect data collected from diverse sources. Accordingly, it is difficult to ensure the accuracy of such research. On a small scale (i.e., county or city level), there have been a number of studies of heritage trees by field investigation [1,8,12]. Nevertheless, most of them only provide a simple description of heritage trees therein [27]. More importantly, these studies applied different methods, thereby making it difficult to compare distribution pattern of ancient trees in different areas. In contrast, there is little research on ancient trees on the medium scale (i.e., provincial or regional level) [10,28,29]. However, studies at this scale can better reveal the spatial differentiation of ancient urban trees in distinct civic space.

A growing body of work has been carried out on reporting the species diversity and spatial distribution of urban heritage trees in a certain region recently. However, little is concerned with the underlying factors [30–32]. Generally, the factors influencing spatial distribution can be divided into two categories, including natural and human factors. The former includes longitude, latitude, topography (e.g., average elevation and elevation range shift) [31], and climate (e.g., mean annual temperature, mean annual precipitation, mean temperature of the warmest month, and mean temperature of the coldest month) [33]. The latter (i.e., anthropogenic influence) can be characterized by GDP per capita and population density [7,34]. For example, a recent study demonstrated that the tree density of old ginkgos in China increased significantly with growth of population density and GDP [16]. Therefore, as urban ancient trees exist for a long time in cities, their diversity and distribution pattern may be comprehensively affected by natural geographical conditions and social human factors, especially in areas with rapid population and urban growth.

Eastern China has witnessed rapid economic development in recent decades. With the increase of urban population, rapid and sustained urbanization may cause dramatic change of ecosystem functions of cities [35,36], thereby inevitably affecting the survival, distribution, and growth of ancient trees. As an eastern–central coastal province of China, Jiangsu has experienced rapid social and economic development over the past four decades. Jiangsu is the third smallest in land area, but the fourth most populous and the most densely populated of the 23 provinces of China, according to the seventh national census. In the past few decades, Jiangsu has witnessed a high level of urbanization. The urban population of Jiangsu rose from 15.2% in 1980 to 73.4% in 2020. Jiangsu had the highest GDP per capita among 31 Chinese provinces and second-highest GDP of those provinces, only behind Guangdong in 2020 [37]. Among China's economic hundred counties in 2020, Jiangsu had 25 of them, accounting for 25%. In addition, each of the 13 cities in Jiangsu has had top counties (i.e., top 100 economic counties of China) in recent years.

The rapid economic development and urban population explosion have caused pressure on local environment and urban heritage trees [12]. Besides, different city histories also affect the preservation and growth of ancient trees. Accordingly, the diversity and distribution of urban ancient trees may be affected by multiple aspects such as climate, geography, population, economic, social, and city history in the process of urbanization.

Here, we took Jiangsu Province in eastern China, which has experienced rapid and sustainable economic development in recent decades, as a typical case. According to provincial forest inventory data, we assessed the abundance, species richness, distribution pattern, and driving factors of heritage trees in this area. Specifically, the object of our study is to: (1) characterize overall species richness and diversity; (2) explore the spatial distribution patterns by cities and tree habitats; (3) determine the leading factor (i.e., climate, geography, and anthropogenic interferences) influencing the distribution pattern; (4) inform scientific baseline and recommendations for management and conservation of heritage trees in Jiangsu and other provinces in eastern China.

2. Methods

2.1. Study Area

Jiangsu Province (30°45′–35°08′ N, 116°21′–121°56′ E) covers 107,200 km^2 of land area. It is located in the central part of the eastern coast region of China. Jiangsu borders Shandong in the north, Anhui to the west, and Zhejiang to the south, and is on the west side of the Yellow Sea. Its landform is mainly plain with multitudinous lakes, and the highest elevation is 624.4 m. It has a warm, temperate humid monsoon climate in the north and subtropical humid monsoon climate in the south. The annual average temperature is 13–16 °C, and the annual average precipitation is 998.5 mm [38]. The main soil types of Jiangsu from north to south are brown soil, leached cinnamon soil, yellow–brown soil, and red–yellow soil. The province covers a forest area of 15,600 km^2, with 24.0% forest coverage rate. Geographically, it can be divided into three subregions: southern Jiangsu (S. Jiangsu), central Jiangsu (C. Jiangsu), and northern Jiangsu (N. Jiangsu), with 13 prefecture-level cities in total (Figure 1). These cities' key information is summarized in Table 1 [37].

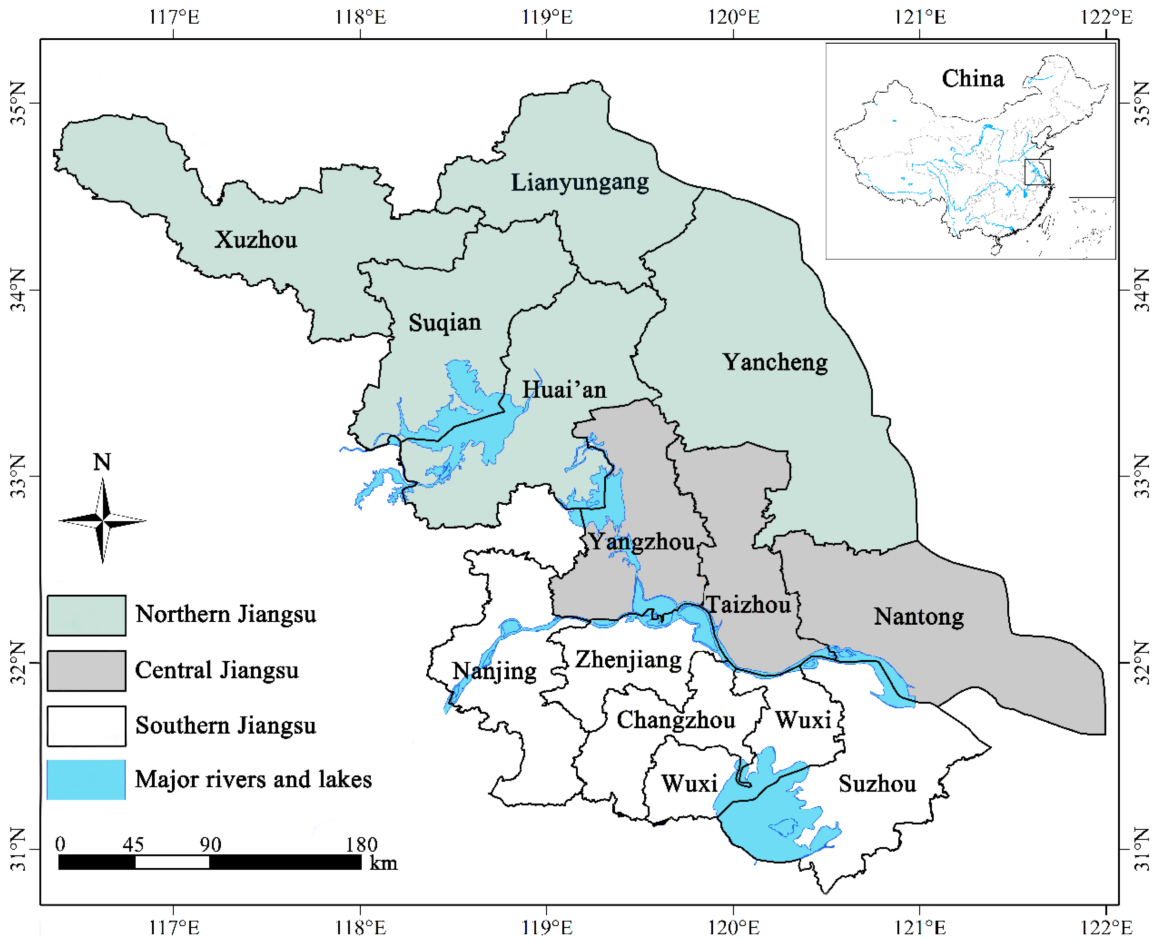

Figure 1. Sketch map of study area of heritage trees in Jiangsu Province, eastern China.

Table 1. Land area, population density, and GDP per capita of 13 cities in Jiangsu Province, eastern China.

Region and District	Abbreviation	Land Area (km^2)	Population Density (Person/km^2)	GDP per Capita ($)
Southern Jiangsu				
Suzhou	SZ	8657	1242	28,089
Wuxi	WX	4627	1425	28,225
Changzhou	CZ	4372	1083	24,517
Zhenjiang	ZJ	3840	834	20,220
Nanjing	NJ	6587	1290	25,974
Central Jiangsu				
Nantong	NT	10,549	694	20,113
Taizhou	TZ	5788	801	17,359
Yangzhou	YZ	6591	690	20,201
Northern Jiangsu				
Yancheng	YC	16,931	426	12,408
Huai'an	HA	10,030	492	12,313
Suqian	SQ	8524	579	12,313
Lianyungang	LYG	7616	592	10,899
Xuzhou	XZ	11,765	750	12,720
Average		8144	838	12,720

2.2. Study Method

Our analysis was based on provincial forest inventory data of field surveys from 2016 to 2020 in Jiangsu Province, which was downloaded from Cloud Platform for Forest Genetic Resources Information of Jiangsu Province (with restricted access). The investigations of ancient trees were made following "*Technical Guidelines for Document Establishment of General Survey of National Ancient-Famous Trees*". It was issued by the State Forestry Bureau in 2001 and has been widely used in China recently [7,12]. Based on tree ages, three protection categories were classified as tier 3 (100–299 years of age), tier 2 (300–499 years of age), and tier 1 ($\geq$500 years of age).

We collated the data of these heritage trees, including their coordinates, diameter at breast height (DBH), tree age, growth status, geographical origin, photos, etc. Firstly, botanical names and taxonomic classifications of all species were identified following the *Flora of China* [39] and the *Catalogue of Life China: 2021 Annual Checklist* (accessed on 30 September 2021). We also checked their species name. For example, the ancient tree was identified as *Zelkova schneideriana* in Nantong, but we corrected its name to *Celtis sinensis* according to its photos and morphological description. According to DBH and tree growth characteristics, we first checked the tree age of each individual, and then removed the records of such trees less than 100 years old. The remained trees were divided into four categories as "good", "fair", "poor", and "dying" by the description of growth status (Table 2) [7,8]. Moreover, nine tree habitat types were classified based on the detailed records of ancient trees' growing sites (Table 3) [1,12]. For geographical origin of species, natives refer to the species naturally occurring in Jiangsu Province while exotics refer to the species cultivated in Jiangsu (Table A1). In addition, a total of 12 ancient trees were deleted because they were recorded as dead, and no further statistical analysis was performed.

Table 2. Gradients division of growth status of heritage trees in Jiangsu Province, eastern China.

Type	Explanation
Good	The heritage tree is vigorous and without suffering disease.
Fair	The heritage tree has minor damage with average growth performance.
Poor	The heritage tree has weak growth performance, as well as slowly growing and serious damage.
Dying	The heritage tree is moribund with mostly withered branches.

Table 3. Nine tree habitat types which accommodate heritage trees were identified in Jiangsu Province, eastern China.

Abbreviation	Tree Habitat Types	Paraphrase
VF	Villages and farmlands	Including rural areas and farmlands where houses far from the city center with small population density, usually close to large areas of croplands.
RC	Religious sites and cemeteries	Including ancestral temples, Taoist temples, and martyr memorial parks, referring to an inner resource.
GC	Government, institutional units and community grounds	Including community centers, village committees, schools, and hospitals which provide social and public services.
EC	Enterprises and commerce places	Including factories, restaurants, and hotels which are usually places for commercial activities to generate revenue.
RD	Residential districts	Including residential quarters and apartments with large population density, usually meeting the needs of life easily.
PG	Parks and gardens	Including scenic areas, public parks, and forest parks, environments which are often protected well.
WP	Wooded areas and plant nurseries	Including bamboo gardens, arboretums, and fruit ranches that have a clear purpose in planting trees.
RS	Roadsides	Including expressways, isolation belts, and arterial traffics where traffic is dense.
OT	Others	Including ferry stations, stations, and pastures which are not well-described or fail to fall into the other eight categories.

2.3. Data Analysis

The species diversity of heritage trees was assessed by Shannon–Wiener index (H), which was calculated as follows:

$$H = -\sum p_i(\ln p_i)$$

In the formula, p_i is the proportion of individuals of species i in the sum of individuals [40].

Tree density (D) was selected as indicator reflecting the distribution pattern of 13 cities in Jiangsu Province:

$$D = N/\log(A)$$

For each city, N is the number of heritage trees and A is the city land area. The formula could avoid the influence of area effects on tree density [41,42].

Because of the sample size (n = 13) being small and not normally distributed, we conducted Spearman rank correlation analysis between the density and number of ancient trees in 13 cities, and then used Mann–Whitney U-test to compare the difference between them.

The distribution pattern and influencing factors of heritage trees were investigated by ordination analysis. We built a habitats × species matrix, analyzing the species composition of ancient trees in different habitats through detrended correspondence analysis (DCA) [12,43]. To understand the relationship between species diversity/tree density and environmental variables, ten factors were selected as explanatory variables to build up the matrix. Those factors can be categorized into three types representing four geographic (i.e., longitude, Long, °; latitude, Lat, °; average elevation, ELE, m; and elevation range shift, ELR, m), four climatic (i.e., mean annual temperature, MAT, °C; mean annual precipitation, MAP, mm; mean temperature of the warmest month, MWMT, °C; and mean temperature of the coldest month, MCMT, °C), and two anthropogenic variables (i.e., GDP per capita, GDPpc, $; population density, PD, person/km^2). These data were obtained from the Bureau of Statistics of Jiangsu Province (http://tj.jiangsu.gov.cn/col/col80733/index.html, accessed on 30 August 2021). In the study, the applicability of different ordination models was determined by the first ordination axis of DCA. Response data had a gradient <3

SD units long, so redundancy analysis (RDA) was recommended. Explanatory variables were converted by lg(x + 1) to eliminate the difference between dimensions. Collinear variables were eliminated based on forward selection, while the significance of each factor was calculated by using a total of 999 Monte Carlo permutation tests [44].

Data collation and analysis was carried out with Excel 2019, DCA and RDA were performed using the Canoco 5.0 software [45], and bar charts were drawn using Origin 2021.

3. Results

3.1. Species Composition and Growth Status

We obtained 7678 records of heritage tree individuals and identified 215 species belonging to 129 genera and 64 families across 13 cities in Jiangsu Province, China (Table A1). The species were grouped in frequency classes as dominant (over 100 trees per species), common ($10 \leq$ trees ≤ 100), rare ($2 \leq$ trees ≤ 9), and solitary (only one tree). Only 12 dominant species were among the four categories, accounting for 5.58% of all species. *Ginkgo biloba* achieved supremacy with 2566 individuals and highest proportion at 33.29%, which was the most typical ancient tree species with an absolute numerical advantage in Jiangsu Province. Except the dominant species, the other three categories had similar proportion of species for about 30% per type.

As shown in Table 4, Rosaceae, Cupressaceae, Fagaceae, and Sapindaceae were the top four families, including 55 species, which accounted for 25.58% of the total species. In contrast, the dominant genera were not pronounced, and the largest genera *Acer* only had six species, representing 2.79% of the total species. In Jiangsu, the majority of the heritage trees were native species (i.e., 119), which accounted for 55.35%, whereas the 96 exotics accounted for 44.56% of total species.

Table 4. The top-ranking ten families and genera with number of heritage tree species in Jiangsu Province, eastern China.

Rank	Family			Genus		
	Name	Number	%	Name	Number	%
1	Rosaceae	20	9.30	*Acer*	6	2.79
2	Cupressaceae	15	6.98	*Pinus*	5	2.33
3	Fagaceae	10	4.65	*Juniperus*	5	2.33
4	Sapindaceae	10	4.65	*Quercus*	5	2.33
5	Fabaceae	9	4.19	*Pyrus*	5	2.33
6	Oleaceae	9	4.19	*Ulmus*	5	2.33
7	Pinaceae	8	3.72	*Yulania*	4	1.86
8	Magnoliaceae	8	3.72	*Euonymus*	4	1.86
9	Lauraceae	7	3.26	*Rosa*	4	1.86
10	Salicaceae	6	2.79	*Diospyros*	4	1.86

In terms of tree age, there were 6110 (79.58%) heritage trees of tier 3 (i.e., the youngest category) corresponding to 208 species, accounting for 96.74% in Jiangsu Province. Compared with tier 3, there were fewer trees classified as tier 1 and 2 with aggregate species of 82 and individuals of 1568, contributing 38.14% of species and 24.42% of heritage trees (Figure 2).

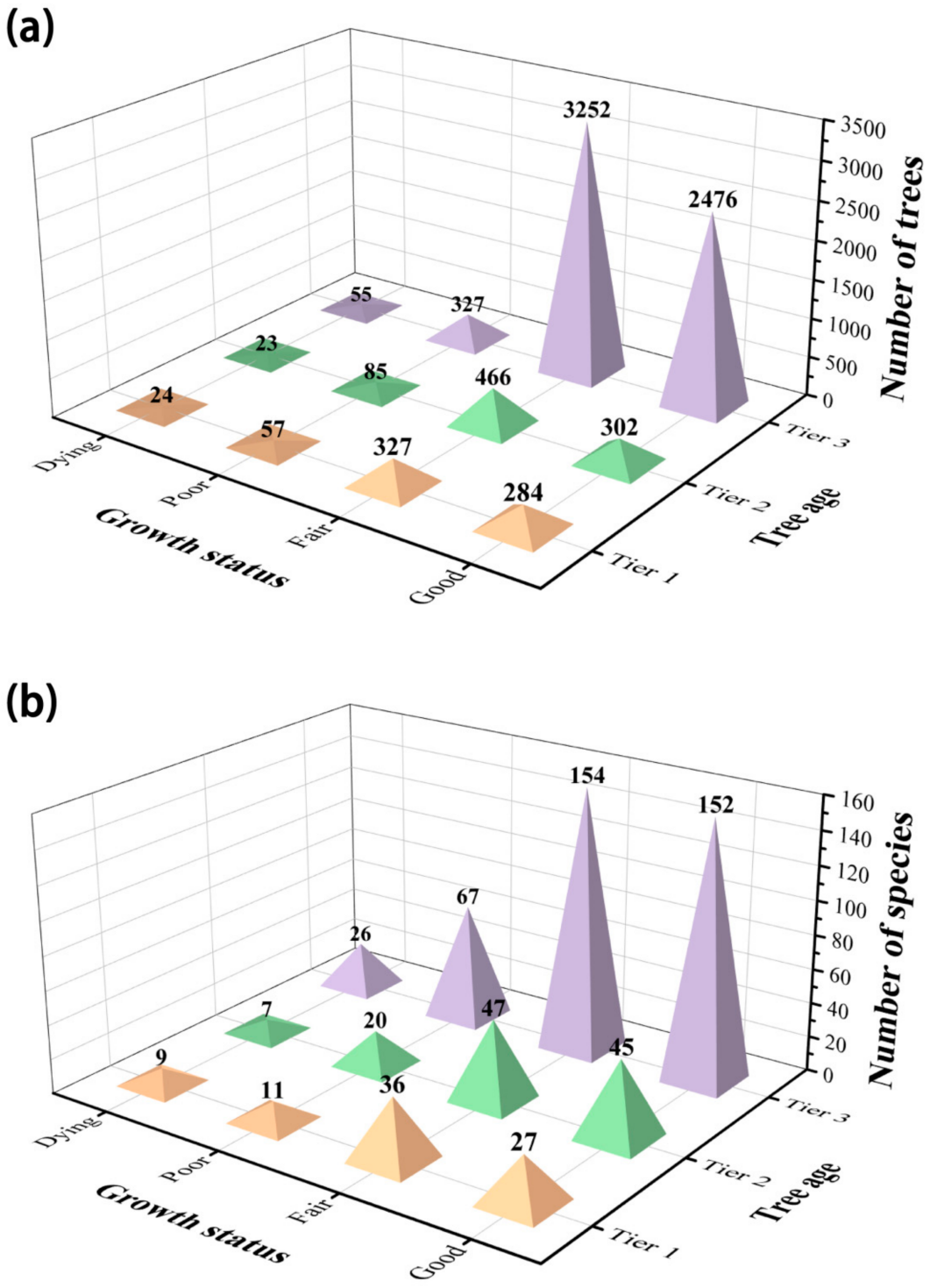

Figure 2. The counts and species of heritage trees in Jiangsu Province, eastern China: (**a**) number of trees; (**b**) number of species across four growth status and three tree ages.

The growth status of ancient trees in Jiangsu Province can be divided into four types: "good" (3062 trees), "fair" (4045 trees), "poor" (469 trees), and "dying" performance (102 trees), accounting for 39.88%, 52.68%, 6.11%, and 1.33% of the whole heritage trees, respectively. In terms of species, the number of "fair" performance was the largest, amounting to 160 species (74.42%). Collectively, the ancient trees in Jiangsu grew well (Figure 2).

3.2. Spatial Distribution and Differentiation by Cities

There was a considerable difference in the distribution of heritage trees among 13 cities of Jiangsu Province. Of them Suzhou ranked the first with 1734 ancient trees (22.58% in total), and far more than the other cities (Figure 3). In terms of species, there were 94 species (43.72%) of ancient trees in Wuxi, followed by Suzhou with 92 species (42.79%) (Figure 3). Conversely, Yancheng had the smallest number of individuals (144 trees, 1.88%) and species (27 species, 12.56%) of heritage trees.

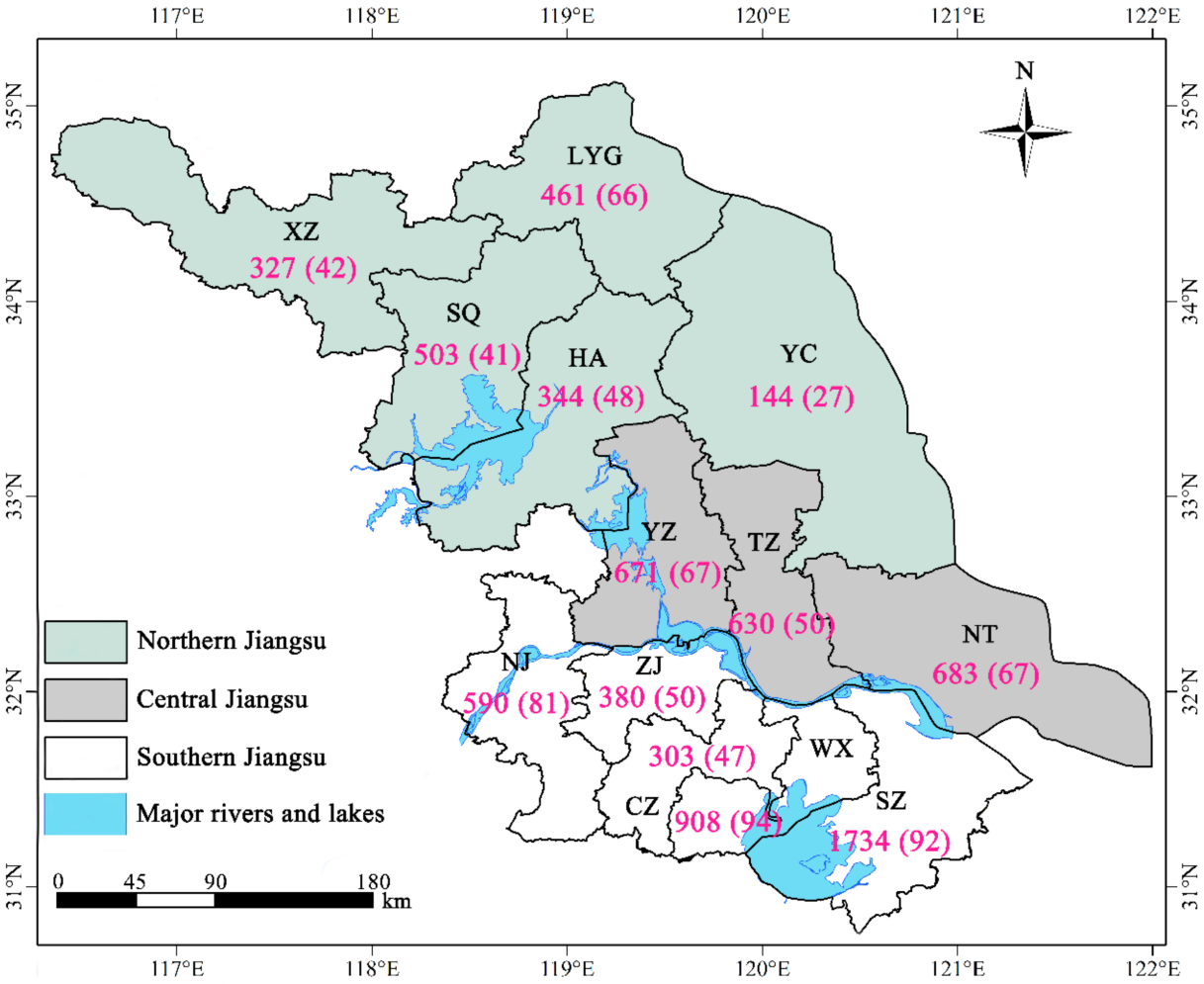

Figure 3. The distribution map showing number and species of heritage trees by 13 cities in Jiangsu Province, eastern China. For each city, the first number on the map indicates individuals, while the second indicates species of heritage trees. Refer to Table 1 for the meaning of the abbreviated cities.

The species diversity index (H) of 13 cities was between 1.98 and 3.39, with the average of 2.77. In light of H, the first three cities were Lianyungang (H = 3.39), Nanjing (H = 3.30), and Huai'an (H = 3.18) (Figure 4a). There was a significantly positive correlation between the tree density of 13 cities and number distribution (r = 0.989, p = 0.000 < 0.01; Z = -3.821, p = 0.000 < 0.01). Suzhou had the largest tree density (D = 440.40), while Yancheng had the lowest (D = 34.05) (Figure 4b).

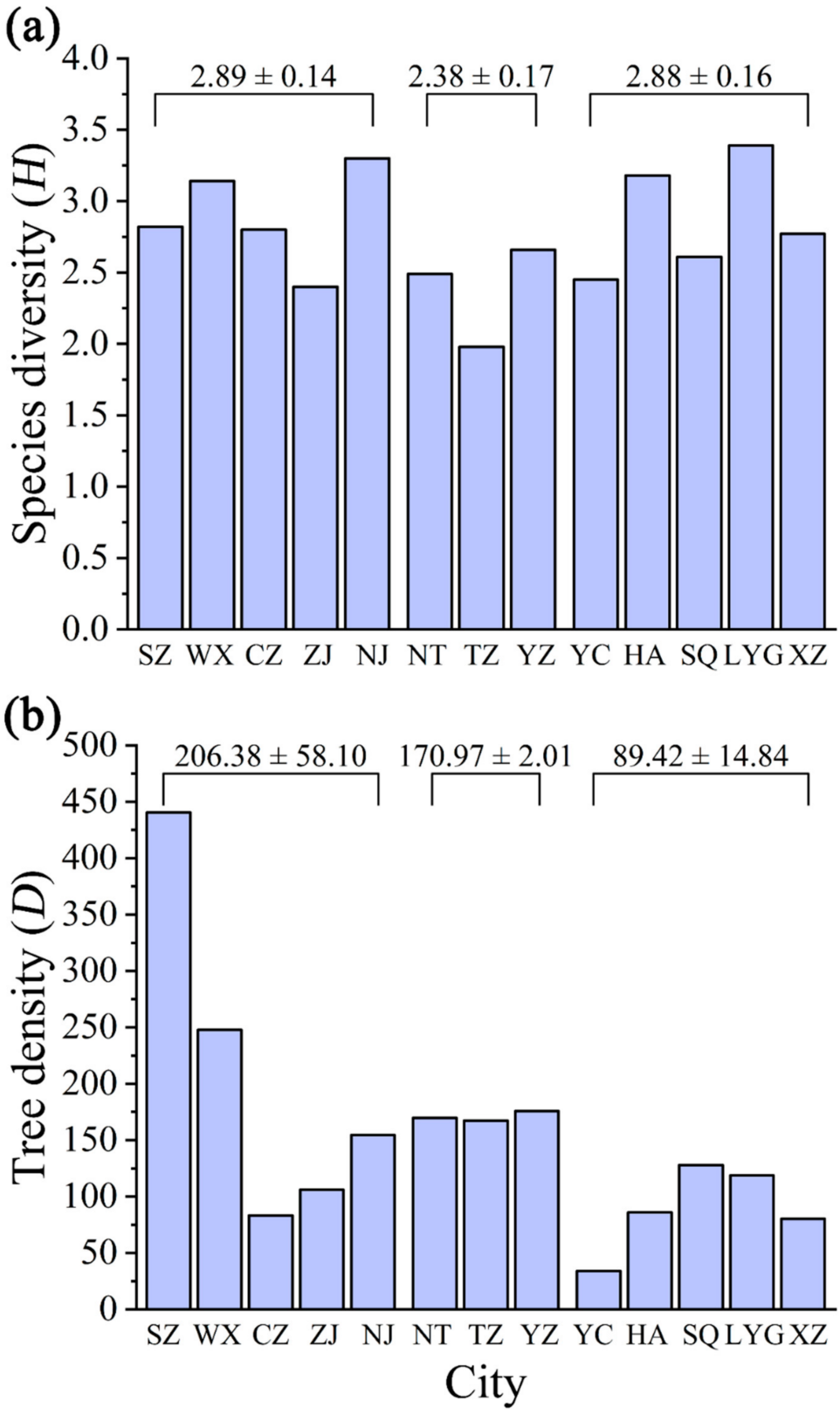

Figure 4. Comparison of spatial distribution by 13 cities in Jiangsu Province, eastern China: (**a**) species diversity and (**b**) tree density. The different data above the bars in (**a**,**b**) indicate the mean ± standard error of southern Jiangsu (including SZ, WX, CZ, ZJ, and NJ), central Jiangsu (NT, TZ, and YZ) and northern Jiangsu (YC, HA, SQ, LYG, and XZ), respectively. Refer to Table 1 for the meaning of the abbreviated cities.

As shown in Figure 5a, the number of four growth states of heritage trees varied greatly in each city. Suzhou had the most heritage trees with "good" growth (i.e., 1101 trees) while Nantong had the most trees with "fair" growth (i.e., 594 trees). For each city, the sum of "good" and "fair" was greater than 90% of the total number of trees, whereas there were very few "poor" and "dying" trees therein (Figure 6a).

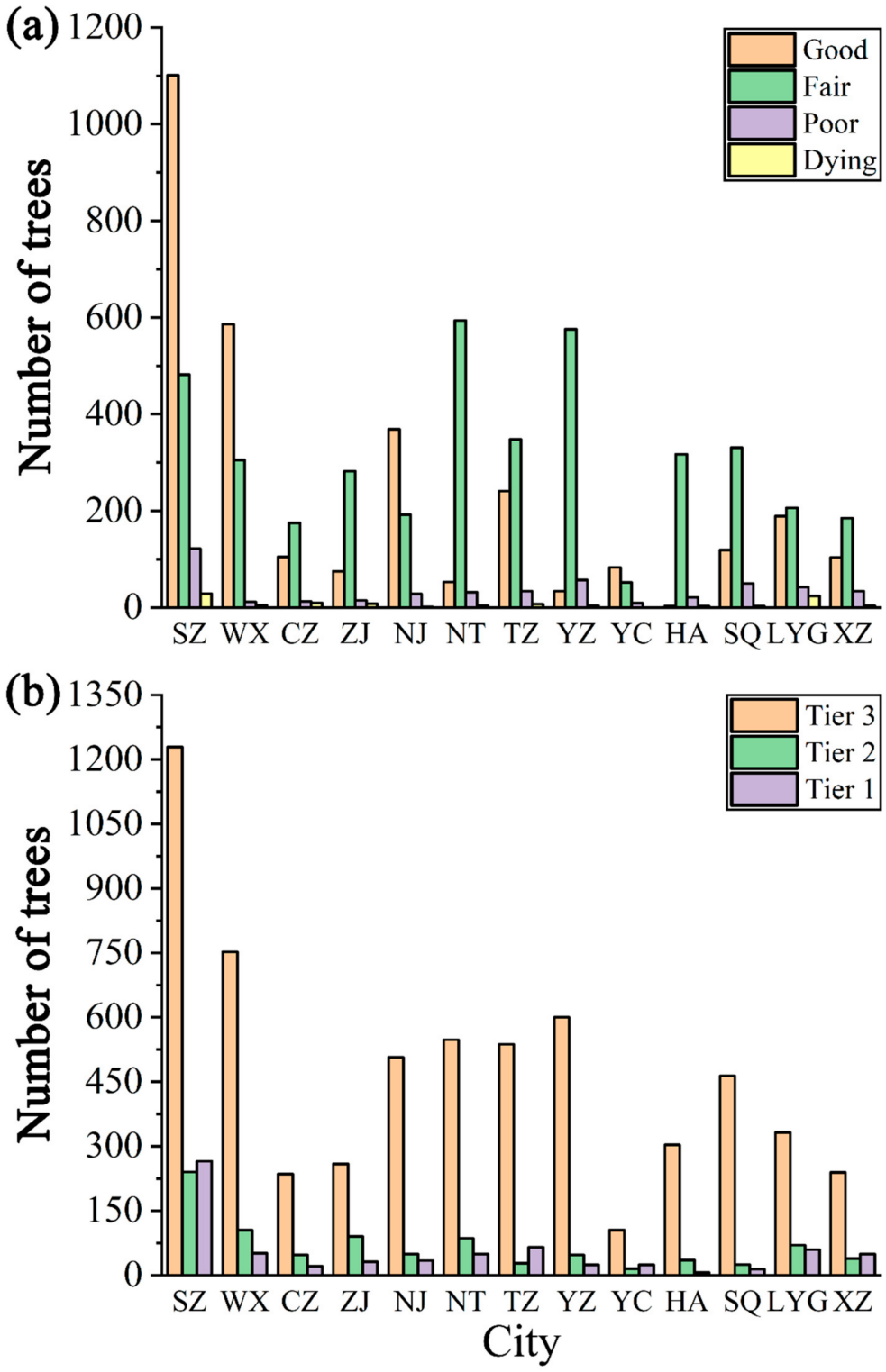

Figure 5. Heritage trees' abundance by growth status (**a**) and tree age (**b**) in 13 cities of Jiangsu Province, eastern China. Refer to Table 1 for the meaning of the abbreviated cities.

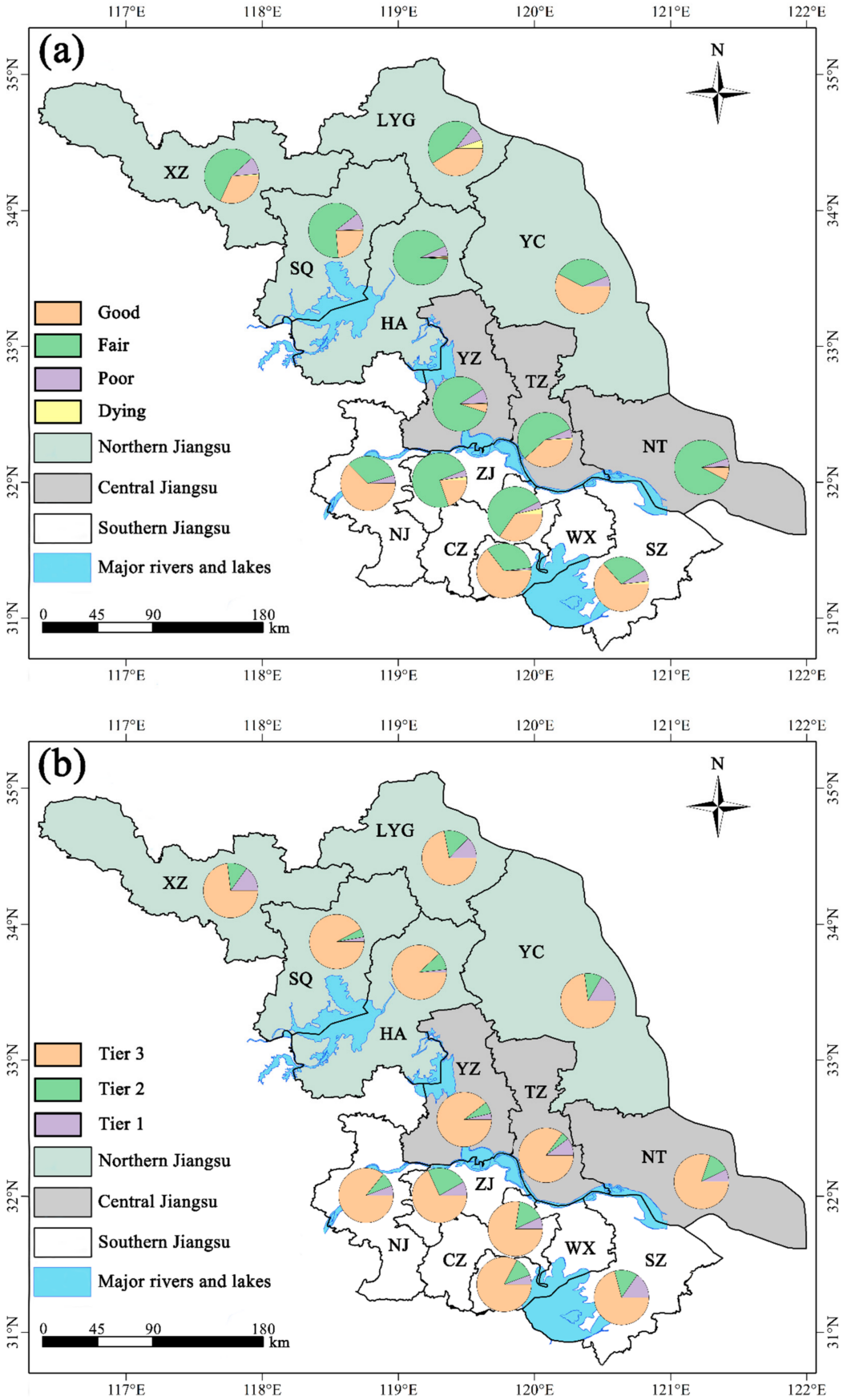

Figure 6. Proportion of growth status (**a**) and tree age (**b**) of heritage trees by 13 cities in Jiangsu Province, eastern China. Refer to Table 1 for the meaning of the abbreviated cities.

Similarly, the age distribution also varied a lot in each city, and the number of tier 3 heritage trees was the largest for each city. Suzhou had the largest number of tier 3 trees (i.e., 1229 trees), followed by Wuxi (i.e., 752 trees), and Yangzhou (i.e., 600 trees), respectively (Figure 5b). For each city, the proportion of tier 3 heritage trees was more than 60%. Suqian had the highest proportion of tier 3 trees, while Zhenjiang had the lowest (68%) (Figure 6b).

3.3. Spatial Distribution and Growth Performance by Tree Habitats

In terms of their number and species, heritage trees were unevenly distributed in different tree habitats. In Jiangsu Province, VF (30.58%) and PG (24.26%) had the first two highest tree counts, followed by RC (14.67%) and GC (14.34%). The number of species distributed in the PG habitat was 149 (69.30%), and 106 species were found in VF habitat ranking the second. GC ranked third with 104 species, while RC ranked fourth with 92 species. RS had the least 108 trees (1.41%) and 26 species (Figure 7a). As expected, PG had the highest biodiversity in light of Shannon–Wiener index, followed by WP and GC (Figure 7b).

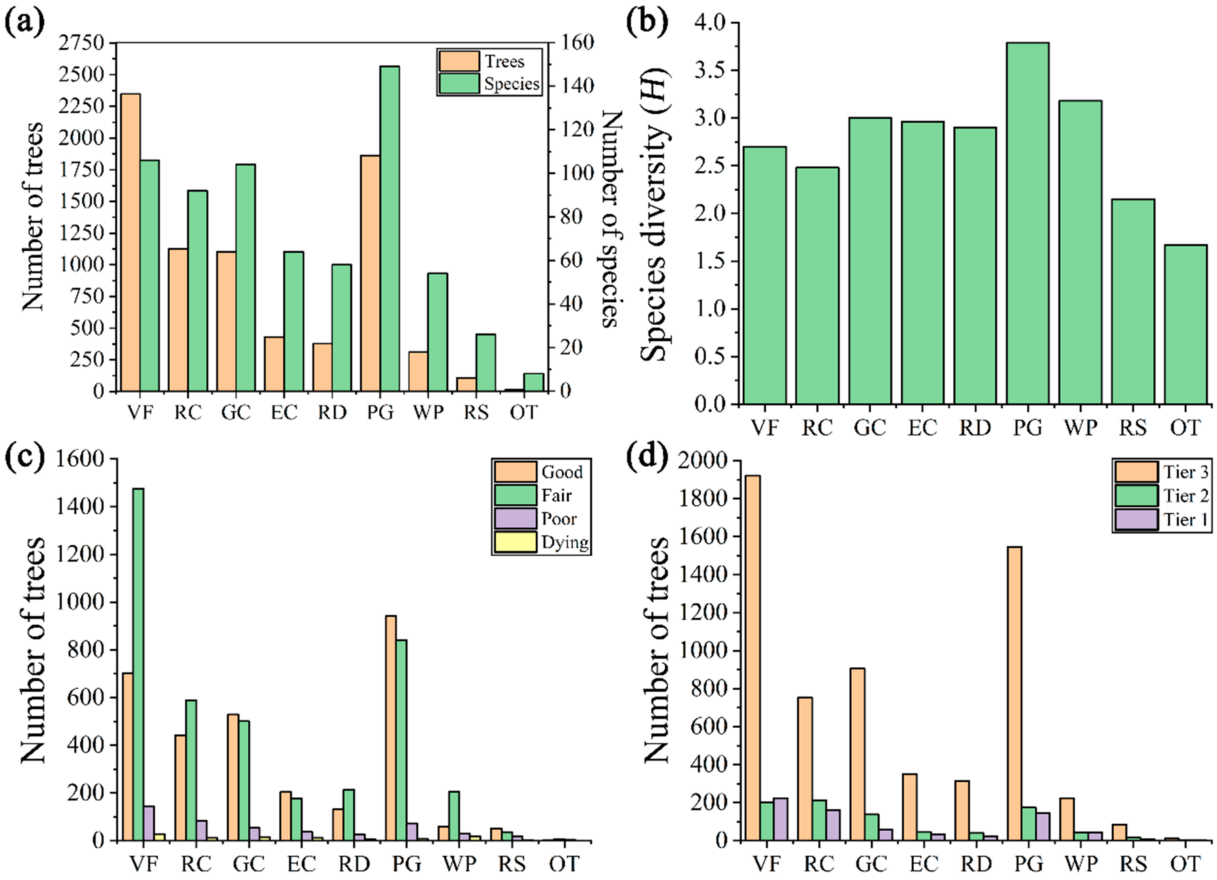

Figure 7. Comparison of spatial distribution by nine tree habitats in Jiangsu Province, eastern China: (**a**) number of trees and species, (**b**) species diversity index, (**c**) abundance by growth status, and (**d**) abundance by tree age. Refer to Table 3 for the meaning of the abbreviated tree habitats.

On the whole, the growth states of ancient trees were mostly "good" and "fair" in different habitats. The distribution of "fair" ancient trees was the largest in the VF habitat, while the PG had the largest number of "good" trees (Figure 7c). Of the nine habitat types, only PG habitat had more than 50% of "good" performance heritage trees (i.e., 50.51%). In each habitat type, "good" and "fair" performances were dominant. Except for OT habitat (71.43%), the sum of "good" and "fair" was greater than 80% in the other eight habitat types.

The age distribution of ancient trees varied largely in terms of habitats. The number of tier 3 heritage trees was the largest in each habitat type. VF had the most tier 1 ancient trees, while RC harbored the most tier 2 ancient trees (Figure 7d). In contrast, ancient trees over 300 years old had a higher proportion in RC and WP.

3.4. Influencing Factors

Species spatial distribution by tree habitats was illustrated in Figure 8. Unique species were found in seven habitats except roadsides and others. Firstly, PG had the most unique species with 41 species. For example, all 17 of *Carya illinoinensis* (No. 94) were restricted to PG, and the species was a "common" species in this study. Secondly, there were 18 unique species in GC, and then 17 unique species, including the nine counts of *Juniperus procumbens* (No. 19), four of *Pyrus calleryan* (No. 115), and three of *Buxus bodinieri* (No. 47), were restricted to VF. *Ginkgo biloba* (No. 2), *Cinnamomum camphora* (No. 31), *Chaenomeles sinensis* (No. 105), and *Celtis sinensis* (Mo. 136) were found in all nine habitats. These species were "dominant" or "common" species in Jiangsu Province. The other nine dominant species (e.g., *Juniperus chinensis*, No. 16; *Zelkova schneideriana*, No. 132; *Osmanthus fragrans*, No. 195, etc.) were found in most habitats.

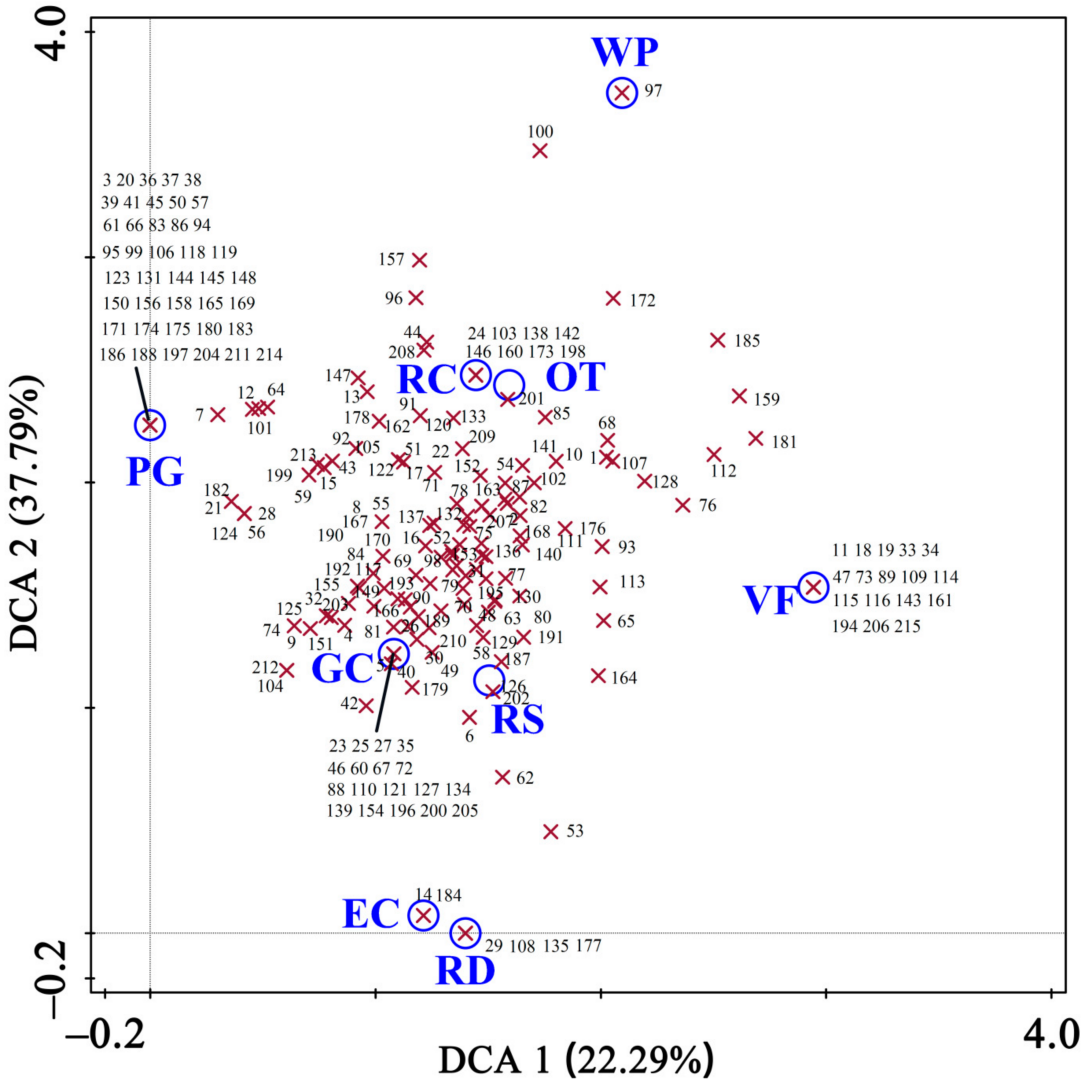

Figure 8. The first two axes of the DCA ordination of nine tree habitats and heritage tree species composition in Jiangsu Province, eastern China. Tree habitat types are presented as circles, and species as crosses. Refer to Table 3 for the meaning of the abbreviated tree habitats, and Table A1 for the numerical order of species names.

Secondly, there were 18 unique species in GC, and then 17 unique species, including nine of *Juniperus procumbens* (No. 19), four of *Pyrus calleryana* (No. 115), and three of *Buxus bodinieri* (No. 47) were restricted to GC.

Ginkgo biloba (No. 2), *Cinnamomum camphora* (No. 31), *Chaenomeles sinensis* (No. 105), and *Celtis sinensis* (Mo. 136) were found in all nine habitats. These species were "dominant" or "common" species in Jiangsu Province. The other nine dominant species (e.g., *Juniperus chinensis*, No. 16; *Zelkova schneideriana*, No. 132; *Osmanthus fragrans*, No. 195, etc.) were found in most habitats.

Nine factors were selected to build an RDA model, which explained 84.1% of the total variation. In this model, axes 1 and 2 explained 84.06% and 15.94% of the total variance, respectively. By screening, ELR was the strongest ($F = 8.4$) and only significant ($p = 0.01$) explanatory variable for the species diversity variation, which explained 43.2% of the total variation, and accordingly was the most important factor affecting the species diversity of heritage trees in Jiangsu. The strength (F-value) of all other drivers included in the RDA was obviously lower, which, ranked by strength, were ELE ($F = 3.9$) > PD ($F = 1.0$) > MAP ($F = 0.5$) > Lat ($F = 0.3$) > MWMT ($F = 0.2$) > MCMT ($F = 0.2$) > GDPpc ($F = 0.2$), while MAT explained very little ($F < 0.1$) of the additional variation (Figure 9a).

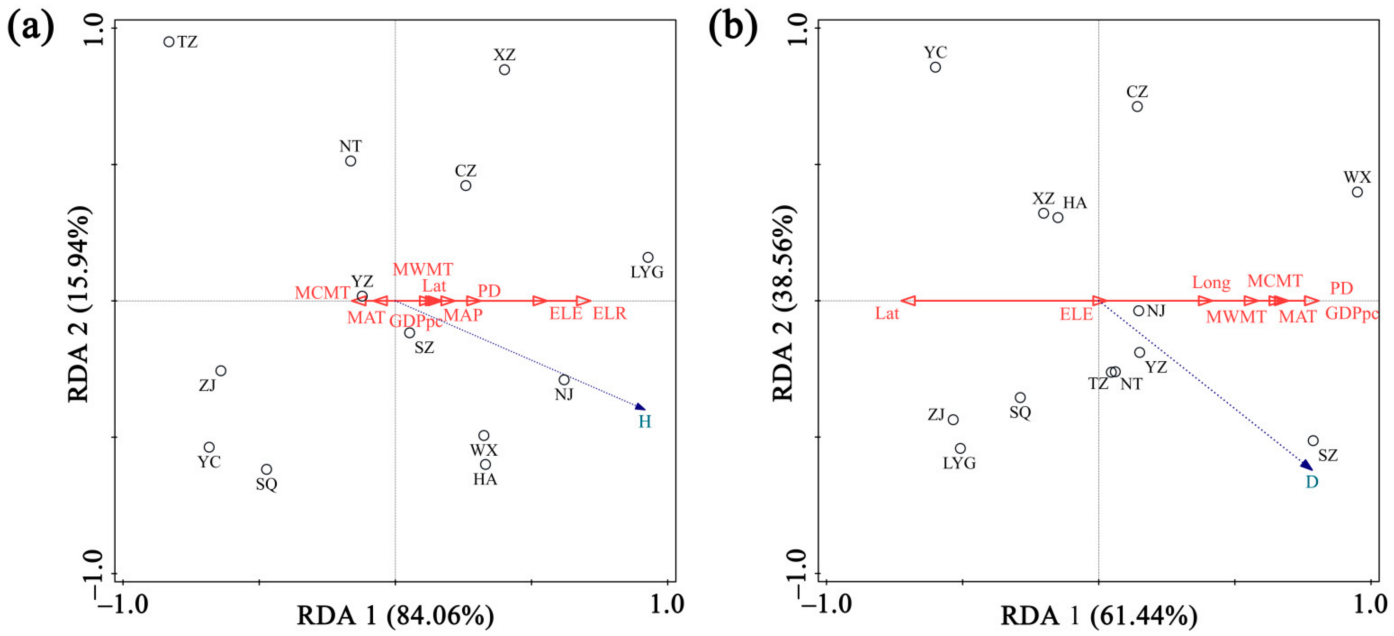

Figure 9. Redundancy analysis between species diversity (**a**), tree density (**b**), and environmental variables, respectively, in Jiangsu Province, eastern China. Blue dashed arrows represent different types of response variables. Red solid arrows represent different environmental factors mentioned in the text. Hollow circles represent the 13 studied cities in Jiangsu. Long: longitude, Lat: latitude, ELE: average elevation, ELR: elevation range shift, MAT: mean annual temperature, MAP: mean annual precipitation, MWMT: mean temperature of the warmest month, MCMT: mean temperature of the coldest month, GDPpc: GDP per capita, PD: population density. Refer to Table 1 for the meaning of the abbreviated cities.

First, ELR explained 51.4% of the model, and then MWMT explained 14.4% of all. The two factors accounted for a total of 57.6% of the variation (68.5% of the model). For MCMT and MAT, RDA identified negative associations with species diversity along the constrained axes.

Eight of the ten factors were selected to generate a better model, which together explained 61.4% of the total variation. The first and second axes accounted for 61.44% and 38.56%, respectively. GDPpc ($F = 7.4$), PD ($F = 7.4$), and Lat ($F = 5.3$) were the three principal explanatory variables of the tree density variation ($P < 0.05$), respectively, explaining 40.1%, 3.6%, and 1.3% of all. The other factors included in the RDA were ranked by F-value from

greatest to least: MAT (F = 4.7) > MCMT (F = 4.3) > MWMT (F = 2.9) > Long (F = 1.3), meanwhile ELE explained very little (F < 0.1) (Figure 9b).

In this model, GDPpc first explained 65.3% of the model, and MCMT explained 8.6% of all. However, no significant correlation existed between MCMT and tree density. There was negative association between Lat and the tree density along the constrained ordination axes.

4. Discussion

4.1. The Heritage Tree Diversity Assessment

As a representative province of rapid urbanization in the eastern coastal areas of China, Jiangsu had 7678 heritage trees belonging to 215 species. The number of heritage trees in Jiangsu is higher than that in Shandong Province (7179 trees) to the north of Jiangsu [15], but much lower than that in Zhejiang Province (65,067 trees, 338 species, 2001; 213, 700 trees, 459 species, 2005) to the south of Jiangsu [13,14].

Jiangsu is mainly characterized by a wide plain and low mountain in topography. Meanwhile, there are many lakes and rivers therein. At the same time, Jiangsu is located in a transition zone between the temperate and subtropical climate [46]. The topography and climate provide distinct microhabitats and hydrothermal conditions for the growth of urban trees. In addition, Jiangsu has the second highest GDP of 31 provinces in mainland China, which provides an economic foundation for the protection of urban heritage trees.

The review of current studies indicates that various indexes have been applied to evaluate the heritage tree diversity in different regions. Generally, they include single index (i.e., number, species, density, etc.) [28,32,47] and composite index (i.e., importance value, Shannon–Wiener index, evenness index, etc.) [1,12]. There is no uniform approach for investigating ancient trees in practice, and, furthermore, such surveys are conducted by different scholars at different time. Accordingly, it is difficult to ensure data accuracy when comparing ancient trees of different areas. For example, Yu (2001) reported that Zhejiang had 65,067 heritage trees of 338 species [13], whereas Du et al. (2005) documented that it had 213,700 trees of 459 species [14]. For reasons given above, it seems difficult to compare the ancient trees among different provinces or large cities.

In the current study, all the data and materials were obtained from provincial forest inventory data, which ensures that the 13 cities have consistent standards and methods for ancient tree survey. Based on the raw data, we then checked each item of heritage trees (e.g., species name, tree habitat, locality, and tree age) so that the reliability of analysis data can be guaranteed in this study.

To our knowledge, this is the first time that species diversity and distribution patterns of heritage trees have been evaluated by a scientific and unified method on the provincial scale. This study can provide a baseline for the protection of ancient trees in Jiangsu Province and offer a scientific reference for heritage tree investigations in other provinces.

4.2. Spatial Pattern of Heritage Trees in Jiangsu Province

There is a significant difference in distribution of heritage trees in Jiangsu Province by cities or by habitats. The results indicate that trees, species, and density of ancient trees declined from south to north (Figures 3 and 4b), mainly resulting from climatic conditions. Compared to C. or N. Jiangsu, S. Jiangsu has the more subtropical humid monsoon climate, with higher mean annual temperature and more precipitation, which may be more suitable for the survival of heritage trees. Many studies have confirmed that ancient trees can better tolerate heat than drought [31,48–50], especially in dry or hot seasons. The Shannon–Wiener diversity index (H) in S. Jiangsu is similar to that in N. Jiangsu, but each of them is higher than that in C. Jiangsu. This may be largely due to different topography. Either S. or N. Jiangsu has relatively higher mountain areas than C. Jiangsu, which mainly comprises plains. Therefore, both S. and N. Jiangsu may harbor much richer tree species than C. Jiangsu, thereby providing the abundant species pool for heritage trees.

Collectively, the distribution pattern of heritage trees of the 13 cities presents a consistent declining trend of three regions from south to north in Jiangsu. However, there is a considerable variation in urban tree number among the 13 cities. Take Nanjing (in S. Jiangsu) as an example: it has more counts of heritage trees than in Yancheng (in N. Jiangsu), but less than in Nantong (in C. Jiangsu). In fact, the differences in urban history, economy level, and cultural tradition play a significant role in urban planning and landscape greening, and they may further affect the abundance, species, and diversity of urban heritage trees [7,51]. Jiangsu has a variety of regional cultures. For example, Lianyungang, Yancheng, and Nantong, bordering the Yellow Sea, boasted navigation and salt-making technology in history, thus developing Marine Culture. In contrast, Changzhou, Wuxi, and Suzhou, surrounding Tai Lake, have been well developed in agricultural and industrial production, thus developing Wu Culture [52]. Wu Culture is characterized by garden construction, which will certainly benefit the bequeath of local heritage trees. Our results demonstrate that species diversity and density of heritage trees in 13 cities of Jiangsu Province may be shaped by different types of influencing factors.

Redundancy analysis (RDA) indicated that diversity of heritage trees was mainly influenced by elevation range shift (ELR) among 13 cities of Jiangsu (Figure 9a). Elevation range shift could be used to reflect habitat heterogeneity [53,54]. Different trees species have distinctive characteristics, thereby affording them extensive adaptability for temperature, water, and elevation ranges. In a certain area, habitat heterogeneity increases with ELR, which can contribute to a greater variety of microhabitats for accommodating more trees [55,56]. Furthermore, there is no remarkable difference in climatic conditions at small and medium geographic scales. Accordingly, topographic heterogeneity is considered as a leading factor influencing distribution pattern of species diversity [57]. Thus, ELR becomes a key factor shaping the spatial differentiation of ancient tree diversity at the medium scale of distribution area.

Unlike species diversity, the heritage tree density of Jiangsu was largely shaped by anthropogenic factors (i.e., GDP per capita, GDPpc; population density, PD) and latitude (Lat) (Figure 9b). This is similar to the results of other studies, in which the density of heritage trees increased with population density [16,49]. GDPpc is the most significant of the three factors. Generally, the higher the GDPpc a city has, the higher its tree density is. In terms of GDPpc, the first two cities are Suzhou and Wuxi, and their corresponding tree densities are also ranked as the top two of the 13 cities (Figure 9b). We notice that in S. Jiangsu, with higher GDPpc where urban residents usually have higher conservation awareness of ancient trees, they may not destroy the urban trees. On the contrary, they are willing to protect trees from insect attack, plant disease, and lightning strikes. Studies have confirmed that higher earners are likely to pay more than lower ones for urban ancient tree conservation [58]. Meanwhile, the local governments in economically developed cities will invest more in the protection of ancient trees. In addition, with the development of economy, citizens expect to have a more comfortable and better environment. Indeed, heritage trees are conducive to improving environmental quality, particularly in densely populated urban areas. Suzhou boasts a developed economy and has high population density. Accordingly, it has the largest density of ancient trees among the 13 cities. Indeed, Suzhou's abundant heritage trees are also linked to classical gardens and city history. Suzhou was founded in 514 BC, with a history of more than 2500 years. There are nine classical Chinese gardens (i.e., Humble Administrator Garden, Lingering Garden, Pavilion of Surging Waves, etc.), which have been listed in the World Cultural Heritage by the United Nations [37]. The ancient trees within these gardens complement city buildings and satisfy people's pursuit for beauty.

Among the nine tree habitats in Jiangsu Province, PG, VF, GC, and RC had the highest numbers and species of heritage trees (Figures 7a and 10b,d,e). DCA showed that over 40% of the 215 species were unique species, which indicates that the relationships between species and habitats is selective. Meanwhile, the four high-diversity habitats predominate with 84 unique species (Figure 8). For example, PG provides a tree habitat with more open,

large, and natural conditions, which can allow heritage trees to flourish with enough room and less stressful environment. Furthermore, this habitat is often used to introduce and cultivate unusual species for ornamental, economic, scientific, and other purposes [59]. For twelve dominant species of heritage trees in Jiangsu, they can be found in most of the nine habitats, indicating that they have no obvious preference for tree habitats. Nine of these dominant species are native, while the other three are exotic. All the three species (i.e., *Ginkgo biloba*) have a long history of cultivation in Jiangsu Province (Figure 10f) [7]. This indicates that all of the 12 species may have adapted to different tree habitats in Jiangsu Province for a long time. In addition, the other reason may be persistent cultivated preference of tree managers [10]. *Ginkgo biloba* is extensively cultivated as ornamental plants or edible nuts in Taizhou, which is known as the Ginkgo Village in China [7]. *Zelkova schneideriana* and *Cinnamomum camphora* are common ornamental tree species in the 13 cities of Jiangsu (Figure 10a,g). *Castanea mollissima* has sweet and edible fruit which can be eaten directly or used as an ingredient in Chinese dishes. Nevertheless, *Styphnolobium japonicum* is often endowed with religious and cultural values in traditional Chinese stories.

Figure 10. Photographs of main heritage trees and their tree habitats in Jiangsu Province, eastern China. (**a**) *Zelkova*

schneideriana in the school (GC); (**b**) *Celtis sinensis* in the government (GC); (**c**) *Gleditsia sinensis* in the roadside (RS); (**d**) *Podocarpus macrophyllus* in the temple (RC); (**e**) *Ulmus parvifolia* in the park (PG); (**f**) *Ginkgo biloba* in the village (VF); (**g**) *Cinnamomum camphora* in the village (VF). The photographs were provided by Zhang G.F.

In addition, compared with the other seven habitats, ancient trees in OT and RS habitats had a higher proportion of poor and dying performance (Figures 7c and 10c), which might be related to their narrow space and strong disturbance.

4.3. Implication for Heritage Tree Conservation and Management

Being economically developed and densely populated, Jiangsu is a rapidly urbanizing province in the eastern coast region of China. Its urbanized population has increased by 58.2% over the past four decades [37]. Nonetheless, there are a large number of well-preserved heritage trees which have been bequeathed in urbanized areas. Most of them grow well in the 13 cities or nine tree habitats because Jiangsu, located in the warm and humid monsoon climate zone, is an economically developed region in eastern China (Table 1). The majority age of 7678 trees is tier 3 (Figure 2), suggesting that they have a great potential of utilization in the near future. These urban heritage trees are becoming assets which may play a significant role in urban landscape construction.

Among the total 215 species of heritage trees in Jiangsu, twelve are dominant species, which contain 5221 trees, accounting for 68.00% of the total. These dominant species demonstrate their adaptability and tenacity despite city development stresses, and they may obtain high recovery capability after experiencing different extent artificial and nature damage. These dominant trees are integral parts of urban greening of Jiangsu since they generally have graceful tree form and dense canopy and can develop a pleasant scent in blossom or bear a large number of fruits/seeds for ornament or food. As a result, they can offer a livable environment for city dwellers. Due to many advantages, they can be regarded as candidate tree species for urban greening and future planning.

Unlike dominant species widely distributed in most of the nine tree habitats, the other heritage tree species have strong preferences or high fidelities to habitats. This probably indicates that land-use change may result in landscape differentiation in quality, quantity, and style during the process of rapid urbanization, thereby shaping the spatial pattern of heritage trees. In fact, there is a considerable variation in number, species, diversity, and health status of these trees (Figure 7). This also reflects the effect of distinctive habitats on urban tree distribution. In such habitats as VF and PG, more urban trees occur with higher species richness because they are protected much better than those in other habitats due to the little influence of urbanization. This implies the need to protect not only the heritage trees themselves from damages, but also their microhabitats. At present, localized management in Jiangsu might have weaknesses for urban heritage trees because it overlooked their habitats and settings. Indeed, distinctive habitat types have obvious effects on distribution of tree species (Figure 8). Therefore, at province scale, protection and management systems of heritage trees should embrace tree habitats and develop individually targeted conservation plans based on current and future land uses.

Heritage trees witness the vicissitudes of a region. Accordingly, the distribution pattern of heritage trees is the result of nature interacting with humans in a province. The distribution of ancient trees in Jiangsu is jointly affected by geographical, climatic, and anthropogenic factors. Based on their analysis of geography and climate, we can identify the species diversity differentiation in different cities, thereby enabling administrative management to create appropriate protection policies. As an example, S. Jiangsu supports most of the individuals and species of heritage trees, most likely because of abundant rainfall, appropriate temperature, and heterogeneous habitats. As such, conservation planning of heritage trees should consider potential threats of environmental changes and extreme climate events (i.e., sustained extreme low temperature in winter). Urban residents' influence for heritage trees has its pros and cons. On the one hand, rapid urbanization and high population density limit the original living space and worsen environmental

stresses for heritage trees, thereby making it difficult to survive or grow. On the other hand, our results indicate that anthropogenic factors (i.e., GDPpc and PD) have a positive and significant impact on tree density (Figure 9b). More specifically, residents and the government have taken considerable measures to protect them, such as hanging tags, designing tree grates, and bracing the trunk. Accordingly, these efforts contribute to making most of them grow well in Jiangsu (Figure 2). In addition, for a city, long history and cultural tradition are also conducive to heritage tree conservation. Therefore, economic level, traditional culture, and urban planning should be integrated into management and conservation plans for heritage trees at the provincial level alongside natural factors.

5. Conclusions

In this study, we took the rapidly urbanizing Jiangsu as a representative province in the eastern coastal areas of China, analyzed its abundance, species richness, tree density, and species diversity of ancient trees in 13 cities, and further explored the spatial differentiation of tree attributes by districts and tree habitats. Our results indicate that species diversity, tree health, and age are associated with tree habitats, and that species diversity among these cities is largely affected by elevation range shift, while the tree density is mainly affected by GDP per capita, population density, and latitude. It was also found that anthropogenic factors (i.e., GDPpc) have a significant effect on heritage tree density. Our findings highlight that management or stakeholders should not only take steps to protect ancient urban trees, per se, but also their habitats and settings (i.e., open space, sufficient light, good soil, etc.) at the provincial level in the future. More importantly, ancient urban trees should be treated as green infrastructure and protected in combination with urban construction and landscape planning. In addition, such protection needs to consider their natural influencing factors, such as topography and climate, and human factors, including social economy, cultural tradition, and urban history, as well.

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

Appendix A

Table A1. Checklist of heritage trees in Jiangsu Province, eastern China. "Native" in the column of "Geographical origin of species" refers to the species naturally occurring in Jiangsu Province while "Exotic" refers to the species cultivated in Jiangsu.

No.	Species Name	Genus Name	Family Name	Geographical Origin of Species
1	*Cycas revoluta*	*Cycas*	Cycadaceae	Exotic
2	*Ginkgo biloba*	*Ginkgo*	Ginkgoaceae	Exotic
3	*Abies firma*	*Abies*	Pinaceae	Exotic
4	*Cedrus deodara*	*Cedrus*	Pinaceae	Exotic
5	*Pinus bungeana*	*Pinus*	Pinaceae	Exotic
6	*Pinus densiflora*	*Pinus*	Pinaceae	Native

Table A1. *Cont.*

No.	Species Name	Genus Name	Family Name	Geographical Origin of Species
7	*Pinus massoniana*	*Pinus*	Pinaceae	Native
8	*Pinus parviflora*	*Pinus*	Pinaceae	Exotic
9	*Pinus thunbergii*	*Pinus*	Pinaceae	Exotic
10	*Pseudolarix amabilis*	*Pseudolarix*	Pinaceae	Native
11	*Chamaecyparis lawsoniana*	*Chamaecyparis*	Cupressaceae	Exotic
12	*Cryptomeria japonica*	*Cryptomeria*	Cupressaceae	Exotic
13	*Cryptomeria japonica* var. *sinensis*	*Cryptomeria*	Cupressaceae	Exotic
14	*Cupressus duclouxiana*	*Cupressus*	Cupressaceae	Exotic
15	*Cupressus funebris*	*Cupressus*	Cupressaceae	Exotic
16	*Juniperus chinensis*	*Juniperus*	Cupressaceae	Native
17	*Juniperus formosana*	*Juniperus*	Cupressaceae	Native
18	*Juniperus pingii* var. *wilsonii*	*Juniperus*	Cupressaceae	Exotic
19	*Juniperus procumbens*	*Juniperus*	Cupressaceae	Exotic
20	*Juniperus virginiana*	*Juniperus*	Cupressaceae	Exotic
21	*Metasequoia glyptostroboides*	*Metasequoia*	Cupressaceae	Exotic
22	*Platycladus orientalis*	*Platycladus*	Cupressaceae	Native
23	*Taxodium distichum*	*Taxodium*	Cupressaceae	Exotic
24	*Taxodium distichum* var. *imbricatum*	*Taxodium*	Cupressaceae	Exotic
25	*Taxodium mucronatum*	*Taxodium*	Cupressaceae	Exotic
26	*Podocarpus macrophyllus*	*Podocarpus*	Podocarpaceae	Exotic
27	*Taxus wallichiana* var. *mairei*	*Taxus*	Taxaceae	Exotic
28	*Torreya grandis*	*Torreya*	Taxaceae	Exotic
29	*Illicium lanceolatum*	*Illicium*	Schisandraceae	Native
30	*Chimonanthus praecox*	*Chimonanthus*	Calycanthaceae	Exotic
31	*Cinnamomum camphora*	*Cinnamomum*	Lauraceae	Native
32	*Cinnamomum longepaniculatum*	*Cinnamomum*	Lauraceae	Exotic
33	*Laurus nobilis*	*Laurus*	Lauraceae	Exotic
34	*Machilus thunbergii*	*Machilus*	Lauraceae	Native
35	*Phoebe chekiangensis*	*Phoebe*	Lauraceae	Exotic
36	*Phoebe sheareri*	*Phoebe*	Lauraceae	Native
37	*Sassafras tzumu*	*Sassafras*	Lauraceae	Native
38	*Liriodendron chinense*	*Liriodendron*	Magnoliaceae	Native
39	*Liriodendron tulipifera*	*Liriodendron*	Magnoliaceae	Exotic
40	*Magnolia grandiflora*	*Magnolia*	Magnoliaceae	Exotic
41	*Michelia figo*	*Michelia*	Magnoliaceae	Exotic
42	*Yulania biondii*	*Yulania*	Magnoliaceae	Exotic
43	*Yulania denudata*	*Yulania*	Magnoliaceae	Exotic
44	*Yulania liliiflora*	*Yulania*	Magnoliaceae	Exotic
45	*Yulania zenii*	*Yulania*	Magnoliaceae	Native
46	*Trachycarpus fortunei*	*Trachycarpus*	Arecaceae	Exotic
47	*Buxus bodinieri*	*Buxus*	Buxaceae	Exotic
48	*Buxus sinica*	*Buxus*	Buxaceae	Native
49	*Buxus sinica* var. *parvifolia*	*Buxus*	Buxaceae	Exotic
50	*Meliosma myriantha*	*Meliosma*	Sabiaceae	Native
51	*Platanus acerifolia*	*Platanus*	Platanaceae	Exotic
52	*Platanus orientalis*	*Platanus*	Platanaceae	Exotic
53	*Nandina domestica*	*Nandina*	Berberidaceae	Exotic
54	*Paeonia suffruticosa*	*Paeonia*	Paeoniaceae	Exotic
55	*Liquidambar formosana*	*Liquidambar*	Altingiaceae	Native
56	*Distylium racemosum*	*Distylium*	Hamamelidaceae	Exotic
57	*Fortunearia sinensis*	*Fortunearia*	Hamamelidaceae	Native
58	*Loropetalum chinense* var. *rubrum*	*Loropetalum*	Hamamelidaceae	Exotic
59	*Parrotia subaequalis*	*Parrotia*	Hamamelidaceae	Native

Table A1. *Cont.*

No.	Species Name	Genus Name	Family Name	Geographical Origin of Species
60	*Euonymus alatus*	*Euonymus*	Celastraceae	Native
61	*Euonymus fortunei*	*Euonymus*	Celastraceae	Native
62	*Euonymus japonicus*	*Euonymus*	Celastraceae	Exotic
63	*Euonymus maackii*	*Euonymus*	Celastraceae	Native
64	*Populus adenopoda*	*Populus*	Salicaceae	Native
65	*Populus tomentosa*	*Populus*	Salicaceae	Exotic
66	*Salix × aureo-pendula*	*Salix*	Salicaceae	Exotic
67	*Salix babylonica*	*Salix*	Salicaceae	Exotic
68	*Salix matsudana*	*Salix*	Salicaceae	Native
69	*Xylosma congesta*	*Xylosma*	Salicaceae	Native
70	*Triadica sebifera*	*Triadica*	Euphorbiaceae	Native
71	*Bischofia polycarpa*	*Bischofia*	Phyllanthaceae	Native
72	*Flueggea suffruticosa*	*Flueggea*	Phyllanthaceae	Native
73	*Albizia julibrissin*	*Albizia*	Fabaceae	Native
74	*Albizia kalkora*	*Albizia*	Fabaceae	Native
75	*Dalbergia hupeana*	*Dalbergia*	Fabaceae	Native
76	*Gleditsia japonica*	*Gleditsia*	Fabaceae	Native
77	*Gleditsia sinensis*	*Gleditsia*	Fabaceae	Native
78	*Ormosia hosiei*	*Ormosia*	Fabaceae	Exotic
79	*Robinia pseudoacacia*	*Robinia*	Fabaceae	Exotic
80	*Styphnolobium japonicum*	*Styphnolobium*	Fabaceae	Native
81	*Wisteria sinensis*	*Wisteria*	Fabaceae	Native
82	*Castanea mollissima*	*Castanea*	Fagaceae	Native
83	*Castanea seguinii*	*Castanea*	Fagaceae	Native
84	*Castanopsis sclerophylla*	*Castanopsis*	Fagaceae	Native
85	*Cyclobalanopsis glauca*	*Cyclobalanopsis*	Fagaceae	Native
86	*Lithocarpus glaber*	*Lithocarpus*	Fagaceae	Native
87	*Quercus acutissima*	*Quercus*	Fagaceae	Native
88	*Quercus aliena*	*Quercus*	Fagaceae	Native
89	*Quercus chenii*	*Quercus*	Fagaceae	Native
90	*Quercus fabri*	*Quercus*	Fagaceae	Native
91	*Quercus variabilis*	*Quercus*	Fagaceae	Native
92	*Myrica rubra*	*Myrica*	Myricaceae	Native
93	*Carya cathayensis*	*Carya*	Juglandaceae	Exotic
94	*Carya illinoinensis*	*Carya*	Juglandaceae	Exotic
95	*Juglans mandshurica*	*Juglans*	Juglandaceae	Native
96	*Juglans regia*	*Juglans*	Juglandaceae	Exotic
97	*Platycarya strobilacea*	*Platycarya*	Juglandaceae	Native
98	*Pterocarya stenoptera*	*Pterocarya*	Juglandaceae	Native
99	*Alnus cremastogyne*	*Alnus*	Betulaceae	Exotic
100	*Carpinus turczaninowii*	*Carpinus*	Betulaceae	Native
101	*Armeniaca mume*	*Armeniaca*	Rosaceae	Exotic
102	*Armeniaca vulgaris*	*Armeniaca*	Rosaceae	Native
103	*Cerasus × yedoensis*	*Cerasus*	Rosaceae	Exotic
104	*Cerasus serrulata*	*Cerasus*	Rosaceae	Native
105	*Chaenomeles sinensis*	*Chaenomeles*	Rosaceae	Native
106	*Crataegus pinnatifida*	*Crataegus*	Rosaceae	Native
107	*Eriobotrya japonica*	*Eriobotrya*	Rosaceae	Exotic
108	*Malus × micromalus*	*Malus*	Rosaceae	Exotic
109	*Malus halliana*	*Malus*	Rosaceae	Exotic
110	*Photinia bodinieri*	*Photinia*	Rosaceae	Exotic
111	*Photinia serratifolia*	*Photinia*	Rosaceae	Native
112	*Pyrus × michauxii*	*Pyrus*	Rosaceae	Exotic
113	*Pyrus betulifolia*	*Pyrus*	Rosaceae	Native
114	*Pyrus bretschneideri*	*Pyrus*	Rosaceae	Exotic
115	*Pyrus calleryana*	*Pyrus*	Rosaceae	Native
116	*Pyrus pyrifolia*	*Pyrus*	Rosaceae	Exotic
117	*Rosa banksiae*	*Rosa*	Rosaceae	Exotic

Table A1. *Cont.*

No.	Species Name	Genus Name	Family Name	Geographical Origin of Species
118	*Rosa banksiae* f. *lutea*	*Rosa*	Rosaceae	Exotic
119	*Rosa banksiae* var. *banksiae*	*Rosa*	Rosaceae	Exotic
120	*Rosa banksiae* var. *normalis*	*Rosa*	Rosaceae	Exotic
121	*Elaeagnus argyi*	*Elaeagnus*	Elaeagnaceae	Native
122	*Elaeagnus pungens*	*Elaeagnus*	Elaeagnaceae	Native
123	*Elaeagnus umbellata*	*Elaeagnus*	Elaeagnaceae	Native
124	*Hovenia acerba*	*Hovenia*	Rhamnaceae	Native
125	*Sageretia thea*	*Sageretia*	Rhamnaceae	Native
126	*Ziziphus jujuba*	*Ziziphus*	Rhamnaceae	Native
127	*Ulmus chenmoui*	*Ulmus*	Ulmaceae	Native
128	*Ulmus laevis*	*Ulmus*	Ulmaceae	Exotic
129	*Ulmus parvifolia*	*Ulmus*	Ulmaceae	Native
130	*Ulmus pumila*	*Ulmus*	Ulmaceae	Native
131	*Ulmus szechuanica*	*Ulmus*	Ulmaceae	Native
132	*Zelkova schneideriana*	*Zelkova*	Ulmaceae	Native
133	*Aphananthe aspera*	*Aphananthe*	Cannabaceae	Native
134	*Celtis biondii*	*Celtis*	Cannabaceae	Native
135	*Celtis bungeana*	*Celtis*	Cannabaceae	Native
136	*Celtis sinensis*	*Celtis*	Cannabaceae	Native
137	*Pteroceltis tatarinowii*	*Pteroceltis*	Cannabaceae	Native
138	*Broussonetia papyrifera*	*Broussonetia*	Moraceae	Native
139	*Ficus pumila*	*Ficus*	Moraceae	Native
140	*Maclura tricuspidata*	*Maclura*	Moraceae	Native
141	*Morus alba*	*Morus*	Moraceae	Native
142	*Morus alba* var. *multicaulis*	*Morus*	Moraceae	Exotic
143	*Euscaphis japonica*	*Euscaphis*	Staphyleaceae	Native
144	*Firmiana simplex*	*Firmiana*	Malvaceae	Native
145	*Tilia henryana* var. *subglabra*	*Tilia*	Malvaceae	Native
146	*Tilia mandshurica*	*Tilia*	Malvaceae	Native
147	*Tilia miqueliana*	*Tilia*	Malvaceae	Native
148	*Edgeworthia chrysantha*	*Edgeworthia*	Thymelaeaceae	Exotic
149	*Lagerstroemia indica*	*Lagerstroemia*	Lythraceae	Native
150	*Lagerstroemia subcostata*	*Lagerstroemia*	Lythraceae	Exotic
151	*Punica granatum*	*Punica*	Lythraceae	Exotic
152	*Pistacia chinensis*	*Pistacia*	Anacardiaceae	Native
153	*Acer buergerianum*	*Acer*	Sapindaceae	Native
154	*Acer buergerianum* var. *yentangense*	*Acer*	Sapindaceae	Exotic
155	*Acer palmatum*	*Acer*	Sapindaceae	Exotic
156	*Acer palmatum* var. *thunbergii*	*Acer*	Sapindaceae	Exotic
157	*Acer pictum* subsp. *mono*	*Acer*	Sapindaceae	Native
158	*Acer truncatum*	*Acer*	Sapindaceae	Native
159	*Aesculus chinensis*	*Aesculus*	Sapindaceae	Exotic
160	*Koelreuteria bipinnata*	*Koelreuteria*	Sapindaceae	Exotic
161	*Koelreuteria paniculata*	*Koelreuteria*	Sapindaceae	Exotic
162	*Sapindus saponaria*	*Sapindus*	Sapindaceae	Native
163	*Citrus medica*	*Citrus*	Rutaceae	Exotic
164	*Citrus wilsonii*	*Citrus*	Rutaceae	Exotic
165	*Orixa japonica*	*Orixa*	Rutaceae	Native
166	*Ailanthus altissima*	*Ailanthus*	Simaroubaceae	Native
167	*Melia azedarach*	*Melia*	Meliaceae	Native
168	*Toona sinensis*	*Toona*	Meliaceae	Native
169	*Tamarix chinensis*	*Tamarix*	Tamaricaceae	Native
170	*Camptotheca acuminata*	*Camptotheca*	Nyssaceae	Native
171	*Cornus officinalis*	*Cornus*	Cornaceae	Exotic
172	*Cornus walteri*	*Cornus*	Cornaceae	Native
173	*Cornus wilsoniana*	*Cornus*	Cornaceae	Exotic
174	*Ternstroemia gymnanthera*	*Ternstroemia*	Pentaphylacaceae	Exotic

Table A1. *Cont.*

No.	Species Name	Genus Name	Family Name	Geographical Origin of Species
175	*Diospyros armata*	*Diospyros*	Ebenaceae	Exotic
176	*Diospyros kaki*	*Diospyros*	Ebenaceae	Exotic
177	*Diospyros kaki* var. *silvestris*	*Diospyros*	Ebenaceae	Native
178	*Diospyros lotus*	*Diospyros*	Ebenaceae	Native
179	*Camellia japonica*	*Camellia*	Theaceae	Exotic
180	*Camellia sasanqua*	*Camellia*	Theaceae	Exotic
181	*Camellia sinensis*	*Camellia*	Theaceae	Native
182	*Symplocos paniculata*	*Symplocos*	Symplocaceae	Native
183	*Sinojackia xylocarpa*	*Sinojackia*	Styracaceae	Native
184	*Rhododendron simsii*	*Rhododendron*	Ericaceae	Native
185	*Eucommia ulmoides*	*Eucommia*	Eucommiaceae	Exotic
186	*Trachelospermum jasminoides*	*Trachelospermum*	Apocynaceae	Native
187	*Ehretia acuminata*	*Ehretia*	Boraginaceae	Native
188	*Ehretia dicksonii*	*Ehretia*	Boraginaceae	Exotic
189	*Lycium chinense*	*Lycium*	Solanaceae	Native
190	*Chionanthus retusus*	*Chionanthus*	Oleaceae	Native
191	*Fontanesia phillyreoides* subsp. *fortunei*	*Fontanesia*	Oleaceae	Native
192	*Fraxinus chinensis*	*Fraxinus*	Oleaceae	Native
193	*Ligustrum lucidum*	*Ligustrum*	Oleaceae	Native
194	*Ligustrum quihoui*	*Ligustrum*	Oleaceae	Native
195	*Osmanthus fragrans*	*Osmanthus*	Oleaceae	Exotic
196	*Osmanthus fragrans* var. *aurantiacus*	*Osmanthus*	Oleaceae	Exotic
197	*Osmanthus fragrans* var. *semperflorens*	*Osmanthus*	Oleaceae	Exotic
198	*Osmanthus fragrans* var. *thunbergii*	*Osmanthus*	Oleaceae	Exotic
199	*Campsis grandiflora*	*Campsis*	Bignoniaceae	Exotic
200	*Campsis radicans*	*Campsis*	Bignoniaceae	Exotic
201	*Catalpa bungei*	*Catalpa*	Bignoniaceae	Native
202	*Catalpa ovata*	*Catalpa*	Bignoniaceae	Native
203	*Catalpa speciosa*	*Catalpa*	Bignoniaceae	Exotic
204	*Vitex negundo*	*Vitex*	Lamiaceae	Native
205	*Vitex negundo* var. *cannabifolia*	*Vitex*	Lamiaceae	Native
206	*Paulownia tomentosa*	*Paulownia*	Paulowniaceae	Native
207	*Pittosporum tobira*	*Pittosporum*	Pittosporaceae	Native
208	*Kalopanax septemlobus*	*Kalopanax*	Araliaceae	Native
209	*Ilex chinensis*	*Ilex*	Aquifoliaceae	Native
210	*Ilex cornuta*	*Ilex*	Aquifoliaceae	Native
211	*Ilex macrocarpa*	*Ilex*	Aquifoliaceae	Exotic
212	*Viburnum macrocephalum*	*Viburnum*	Adoxaceae	Exotic
213	*Viburnum macrocephalum* f. *keteleeri*	*Viburnum*	Adoxaceae	Native
214	*Viburnum odoratissimum* var. *awabuki*	*Viburnum*	Adoxaceae	Exotic
215	*Lonicera maackii*	*Lonicera*	Caprifoliaceae	Native

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