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# Species Composition and Diversity of Middle-Aged Trees among Different Urban Green Space Types and Tree Age Classes in Changchun, Northeast China

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**Abstract:** Middle-aged trees refer to trees aged between 50 and 99 years, which are the reserve resources of old trees (trees $\geq$ 100 years of age). They are vital parts of the urban ecosystem, with important ecological, landscape, cultural, and historical value. Conservation of middle-aged trees in urban areas is important for the development of large old trees in the future. In this study, we investigated the middle-aged trees in Changchun city and analyzed the species composition and diversity characteristics of different urban green space types and tree age classes. The results showed that there were 72 species and 22,376 plants of middle-aged trees in Changchun city, and the coniferous species prevailed. The top five species with a high importance value (IV) were *Pinus tabuliformis* var. *mukdensis*, *Lavix olgensis*, *Salix matsudana*, *Ulmus pumila*, and *Abies holophylla*. Green space type and tree age were important factors influencing the richness and diversity of middle-aged trees. Tree growth spaces were relatively sufficient, and land use was stable for park green spaces (PGS) and attached green spaces (AGS), which resulted in the abundant, richer, and diverse species richness (SR) of middle-aged trees. Road green spaces (RGS) and square green spaces (SGS) had fewer trees and lower species richness, Margalef richness index (dMa), Shannon–Wiener index ($H_e$) and evenness index ($J_e$) which could be attributed to the high intensity of human interference and poor environmental quality. The SR of middle-aged trees decreased with an increase in age class, and the values of SR in Age Class 80–89 years and Age Class 90–99 years were lower than in Age Class 50–59 years. Age Class 70–79 years had the lowest values of dMa, $H_e$, and $J_e$, which need to be protected urgently. The results of this study can provide a basis for the conservation and management of middle-aged trees in urban areas and the choice of species for urban greening.

**Keywords:** middle-aged trees; urban ecosystem; species diversity; green space type; tree age



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## 1. Introduction

Middle-aged trees refer to trees aged between 50 and 99 years, which are the reserve resources of old trees (tree $\geq$ 100 years of age) [1,2]. These trees have great potential to become large old trees in the future [3]. Old trees are keystone structures in forests, woodlands, and agricultural ecosystems, playing unique ecological roles that are not provided by younger trees [4]. Some studies have shown that large and big-sized trees are key elements for carbon storage [5–7], and the rate of tree carbon accumulation increases continuously with tree size [7]. In addition, old trees can create microclimate and microhabitat heterogeneity, such that epiphyte species richness and abundance increase with tree size [4,8]; provide irreplaceable habitats; and act as stepping stones for many animals [4]. Moreover, old trees are an important part of cultural heritage and can provide people with aesthetic, symbolic, religious, and historical cues [9]. Middle-aged trees, as important reserve resources for future large old trees, have great potential to provide richer and multifunctional ecosystem services, such as high ecological, historical, cultural, and landscape value [3].

In the past 20 years, a series of studies have been carried out on old trees, mainly focusing on the investigation of old trees, species diversity, and spatial differentiation characteristics [10–17]. Some studies have shown that the destruction of old trees is serious, and the number of old trees has been reduced sharply [4,18]. With the recognition of the importance of old trees [11,18–25], a number of conservation management measures for old trees have been carried out [26–28]. In the urban ecosystem, old trees are also considered keystone structures that have an important function in urban landscapes [29], such as their role in carbon sequestration, stormwater runoff reduction, heat island effect alleviation, atmospheric pollution mitigation [30], and heritage effects [31–33]. In addition, they can provide important habitat resources for wildlife [29]. Compared with old trees, middle-aged trees have received less attention from the government and society [34]. Only a handful of studies have focused on the surveying, diversity analysis, and conservation of middle-aged trees in the urban ecosystem [18,22,25]. Although middle-aged trees are smaller in DBH and tree height than old trees, they have good growth status, stable community structures, and powerful ecological services [35]. However, the location, function, habitats, and management objectives vary greatly for different types of urban green spaces. Performing a thorough investigation of middle-aged trees in different types of green spaces and ascertaining their age structure, species composition, and diversity are necessary to maintain the stability and sustainable development of the urban ecosystem.

Changchun is one of the fastest growing cities in Northeast China and has a special historical process. Changchun was the capital of "Manchukuo" from 1931 to 1945, and the construction of an East Asian metropolis began in 1932 [23]. Some trees planted in the period of "Manchukuo" are still alive today. Learning from the experience of public green space construction in the former Soviet Union [36], a large number of trees were planted in the city's green spaces in the early years of the founding of the People's Republic of China, and these trees have become important middle-aged trees. In the past 40 years, Changchun has experienced a period of rapid urban development [24]. With the continuous expansion of the city, the inner space of the city has become increasingly crowded, and the environmental pressure on middle-aged trees is also increasing. How to protect and make good use of these precious resources has become an urgent issue. The purposes of this study were (1) to determine the species, richness, and importance value (IV) of the middle-aged trees in Changchun city; (2) to clarify the species composition and diversity characteristics of middle-aged trees in different types of green spaces; and (3) to clarify the species composition and diversity characteristics of middle-aged trees in different age classes. This study can provide a basic reference for the conservation of middle-aged trees and the plant community configuration for ecological garden construction in the rapid urban development period.

## 2. Materials and Methods

### 2.1. Study Area

Changchun city, the capital city of Jilin Province, is located in the middle latitude zone of the Northern Hemisphere (43°05′~45°15′ N, 124°18′~127°05′ E) and situated at east of Eurasia in the hinterland of the Northeast China plain. The built-up area is about 543 km$^2$, and the urban population is around 4.451 million. Changchun has a mid-temperate continental monsoon climate, with an average annual temperature of 4.8 °C, annual precipitation of 522~615 mm, and annual sunshine hours of 2688 h. Soil types are mainly black soil, meadow soil, and chernozem [37].

### 2.2. Habitat Classification of Middle-Aged Trees

According to the location, function, habitats, management objectives and growth environment of middle-aged trees [38], and classification standard of urban green spaces [39], the growth environment of middle-aged trees was divided into four types of green spaces in Changchun city (Table 1). They were all public green spaces, including park green spaces (PGS), road green spaces (RGS), square green spaces (SGS), and attached green spaces (AGS).

**Table 1.** Four tree habitats that accommodate middle-aged trees in Changchun city.

| Types of Green Spaces | Abbreviation | Tree Habitats | Management Department |
|---|---|---|---|
| Park green spaces | PGS | Green spaces of comprehensive park, community park, special park, theme park | Management center of different parks |
| Road green spaces | RGS | Green spaces along railroads, highways, boulevards, roads, and streets | Garden and green department of Changchun city |
| Square green spaces | SGS | Green spaces of city squares and traffic circles | Garden and green department of Changchun city |
| Attached green spaces | AGS | Green spaces attached to government agencies, institutions, hospitals, hotels, public service facilities, schools, colleges, universities, and factories | Management by government agencies, institutions, hospitals, hotels, public service facilities, schools, colleges, universities, and factories |

### 2.3. Field Survey

A field survey was conducted from April to September 2018. A total of 632 sample plots in 59 sites were surveyed, which included 411 plots in 12 sites for PGS, 171 plots in 36 sites for AGS, 21 plots in 6 sites for RGS, and 29 plots in 5 sites for SGS. The area of each plot was 400 $m^2$. The area of each site was different according to the boundary, and woody plants in each plot were all investigated. The species names and abundances were recorded, and the diameter at breast height (DBH) was measured at 1.3 m above the ground. The trees in the sample plots were planted by the Garden Bureau, enterprises, and institutions and were not privately owned. The species were grouped into six classes according to the literature [11], 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 planting records, and trees with no planting records were determined using growth cones. For some species where tree age could not be determined, 30 trees for each species of different types of green spaces were selected to determine the tree age using growth cones, and the DBH was measured with diameter tape; then, the average annual growth of DBH of these species was calculated, and the tree age was estimated based on the average annual growth of DBH.

### 2.4. Data Analysis

After the field survey and data collation, species diversity indexes for the middle-aged trees in each site were calculated. The indexes included species richness (SR), Margalef richness index (dMa) [40], Shannon–Wiener index ($H_e$) [41,42], and evenness index ($J_e$) [43]. These were used to analyze the difference in tree species composition and diversity by different types of urban forests and different age classes. The importance value (IV) for each species was also calculated to indicate their status and role in the ecosystem [30].

$$\text{dMa} = \frac{S-1}{\ln N} \quad (1)$$

$$\text{Shannon-Wiener index: } H_e = -\sum P_i \ln P_i \quad (2)$$

$$\text{Evenness index: } J_e = H_e/\ln S \quad (3)$$

$$\text{Importance value: IV} = (RA_i + RD_i + RF_i)/3 \quad (4)$$

where $S$ = total number of species in each site; $P_i$ = proportion of individuals of $i$th species; $RA$ = relative abundance; $RA_i$ = number of trees in $i$th species/total numbers of trees in eah site; $RD$ = relative dominance, $RD_i$ = basal area at breast height of $i$th species/total basal area in each site; $RF_i$ = frequency of $i$th species/total species frequency in each site.

One-way analysis of variance was performed to test the differences in the species diversity indexes of middle-aged trees among the different types of green spaces and among the different age classes. It is assumed that there is no significant difference in each diversity index between different types of urban forests and different age classes. Multiple comparison tests were used to test the significance of more than two categories. When the variances were homogeneous, Tukey tests were used; otherwise, Games–Howell tests were used. Principal component analysis (PCA) was applied to assess the effects of forest type and age class on middle-aged tree species composition, and species richness was the variable. Similarity percentage (SIMPER) analysis was adopted to assess the species differentiation among the different types of green spaces and age classes. Prior to SIMPER analysis, the species richness was square-root transformed and standardized by normalization. SIMPER analysis was used to examine the contribution of each species to the average Bray–Curtis dissimilarity between the different types of green spaces and the contribution of each species to the average Bray–Curtis dissimilarity among the different age classes. PCA ordination was performed with Canoco 5.0 (Centre for Biometry, Wageningen, The Netherlands). SIMPER analysis was performed with PRIMER version 5.0 (Primer-E Ltd., Roborough, UK). Heatmaps of species dissimilarity for both urban green space types and age classes were generated in R using the pheatmap package.

## 3. Results

### *3.1. Species Composition and Importance Value of Middle-Aged Trees in Changchun*

There were 22,376 middle-aged trees in Changchun city, which belonged to 72 species, 42 genera, and 25 families. Among them, there were 15 coniferous species with 14,927 trees (66.71% in total), 53 deciduous broad-leaved species with 7307 trees (32.66%), and 4 shrubs with 142 trees (0.63%). The ratio of the number of coniferous trees to broad-leaved trees was 1.00:0.49, which indicates that the coniferous species prevailed. The results of species composition showed that the contributions of individual species were highly heterogeneous (Table 2). The signature group had 14 species but accounted for 91.74% of the number of the total trees and had an IV of 78.51%. *Pinus tabuliformis* var. *mukdensis*, *Lavix olgensis*, *Salix matsudana*, *Ulmus pumila*, *Abies holophylla*, *Picea koraiensis Armeniaca sibirica*, and *Fraxinus mandshurica* were the most important 8 species, and the IV of these species reached 64.45%. The dominant group and common group contained 7 and 9 species, which accounted for 3.96% and 2.83% of the total trees and had an IV of 7.33% and 7.51%, respectively. The occasional group had 15 species, which accounted for 1.19% of the total trees and had an IV of 3.74%. The rare category encompassed the highest species number, which comprised 26.39% of the species and 0.27% of the trees, with an IV of 2.41%. The 8 species in the solitary group contributed to only 0.04% of species and 0.51% of IV.

The species composition of middle-aged trees was heavily biased toward native species. A total of 57 species were native and owned 18,593 trees, contributing to 79.17% of species and 83.09% of trees. There were 11 species of 3765 trees from other regions of China, accounting for 15.27% of total species and 16.82% of total trees. Only 4 species were alien with 18 trees, accounting for 5.56% and 0.08% of the total species and trees, respectively. The alien species were *Pinus strobus*, *Acer negundo*, *Robinia pseudoacacia*, and *Populus canadensis*, respectively.

The analysis of IV for different families showed that *Pinaceae* had the highest IV, with a value of 49.37%, followed by *Salicaceae*, with a value of 15.17%. For different genera, *Pinus* had the highest IV of 22.84%, followed by *Larix* and *Salix*, with a value of 13.31% and 10.32%, respectively. In addition, the species with a higher IV in the different types of green spaces varied greatly (Table 3). The IV of *Pinus tabuliformis* var. *mukdensis* in SGS, AGS, and PGS was the highest and ranked second in RGS. *Lavix olgensis* had the highest IV in RGS and ranked second in PGS.

**Table 2.** Species frequency, relative frequency (RF), relative abundance (RA), relative dominance (RD), and species importance value (IV) in Changchun.

| Species Name | Abundance | Species Frequency | RF (%) | RA (%) | RD (%) | IV (%) |
|---|---|---|---|---|---|---|
| *Lavix olgensis* Henry | 5818 | Signature | 3.84 | 26.00 | 8.11 | 12.65 |
| *Pinus tabuliformis* var. *mukdensis* (Uyeki ex Nakai) Uyeki | 3552 | Signature | 8.38 | 15.87 | 21.60 | 15.28 |
| *Abies holophylla* Maxim. | 2035 | Signature | 6.98 | 9.09 | 5.22 | 7.10 |
| *Ulmus pumila* L. | 1466 | Signature | 6.11 | 6.55 | 11.08 | 7.91 |
| *Pinus koraiensis* Siebold et Zuccarini | 1349 | Signature | 1.40 | 6.03 | 1.75 | 3.06 |
| *Picea koraiensis* Nakai | 1347 | Signature | 4.19 | 6.02 | 6.21 | 5.47 |
| *Fraxinus mandshurica* Rupr. | 1294 | Signature | 2.27 | 5.78 | 3.19 | 3.75 |
| *Salix matsudana* Koidz | 937 | Signature | 5.93 | 4.19 | 15.23 | 8.45 |
| *Phellodendron amurense* Rupr. | 639 | Signature | 3.32 | 2.86 | 2.20 | 2.79 |
| *Maackia amurensis* Rupr. et Maxim | 525 | Signature | 1.75 | 2.35 | 1.19 | 1.76 |
| *Pinus sylvestris* var. *mongolica* Litv. | 506 | Signature | 3.49 | 2.26 | 2.24 | 2.66 |
| *Armeniaca sibirica* (L.) Lam. | 472 | Signature | 6.98 | 2.11 | 2.42 | 3.84 |
| *Tilia amurensis* Rupr. | 321 | Signature | 2.27 | 1.43 | 2.59 | 2.10 |
| *Malus baccata* (L.) Borkh | 261 | Signature | 2.44 | 1.17 | 1.44 | 1.68 |
| *Salix babylonica* L. | 173 | Dominant | 1.75 | 0.77 | 2.70 | 1.74 |
| *Padus avium* Miller | 165 | Dominant | 2.97 | 0.74 | 1.31 | 1.67 |
| *Syringa oblata* Lindl. | 123 | Dominant | 0.17 | 0.55 | 0.13 | 0.29 |
| *Larix gmelinii* (Rupr.) Kuzen. | 113 | Dominant | 0.87 | 0.51 | 0.60 | 0.66 |
| *Populus pseudo simonii* Kitagawa | 110 | Dominant | 2.44 | 0.49 | 2.43 | 1.79 |
| *Quercus mongolica* Fischer ex Ledebour | 102 | Dominant | 1.22 | 0.46 | 0.58 | 0.75 |
| *Betula platyphylla* Suk. | 100 | Dominant | 0.52 | 0.45 | 0.33 | 0.43 |
| 9 Common | 633 | Common | 14.49 | 2.83 | 5.21 | 7.51 |
| 15 Occasional | 266 | Occasional | 8.38 | 1.19 | 1.65 | 3.74 |
| 19 Rare | 61 | Rare | 6.46 | 0.27 | 0.49 | 2.41 |
| 8 Solitary | 8 | Solitary | 1.40 | 0.04 | 0.10 | 0.51 |

**Table 3.** Two preponderant species of middle-aged trees by type of green spaces in Changchun city. RGS, road green spaces; SGS, square green spaces; AGS, attached green spaces; PGS, park green spaces.

| Type of Green Space | Preponderant Species | IV (%) | Preponderant Species | IV (%) |
|---|---|---|---|---|
| RGS | *Lavix olgensis* | 40.72 | *Pinus tabuliformis* var. *mukdensis* | 17.96 |
| SGS | *Pinus tabuliformis* var. *mukdensis* | 27.24 | *Populus xiaohei* | 12.08 |
| AGS | *Pinus tabuliformis* var. *mukdensis* | 13.98 | *Salix matsudana* | 13.69 |
| PGS | *Pinus tabuliformis* var. *mukdensis* | 15.08 | *Lavix olgensis* | 12.81 |

### *3.2. Structural Characteristics and Distribution of Middle-Aged Trees among Different Types of Green Spaces*

The distribution of middle-aged trees in the different types of green spaces showed that PGS had the largest number of trees, followed by AGS and RGS, while SGS had the lowest number of trees, with 11,748, 6676, 3481, and 471 trees, accounting for 52.50%, 29.84%, 15.56%, and 2.10% of the total middle-aged trees, respectively (Figure 1a). Furthermore, the number of middle-aged trees between 50–59 years was the highest, accounting for 55.66% of the total trees, followed by Age Class 70–79 years and Age Class 60–69 years, accounting for 28.72% and 12.67% of the total trees, respectively (Figure 1a). However, the number of trees in Age Class 80–89 years and Age Class 90–99 years was lower than in other age classes, which accounted for 2.19% and 0.77%, respectively. As for different types of green spaces, PGS had the highest number of trees in different age classes, but SGS was the lowest.

The distribution of middle-aged trees in different DBH grades showed that the number of trees at the DBH grade of 20–40 cm was the highest, followed by the DBH grade of 41–60 cm and the grade of <20 cm, and the number of trees at the DBH grade of >80 cm was the lowest, which accounted for 54.85%, 22.35%, 17.74%, and 1.18% of the total trees, respectively (Figure 1b). At the range of DBH <20 cm, 21–40 cm, and 41–60 cm, PGS had the largest number of trees, and SGS had the lowest number of trees. However, at the range of 61–80 cm and >80 cm, AGS had the highest number of trees, followed by PGS and RGS, and SGS had the lowest number of trees.

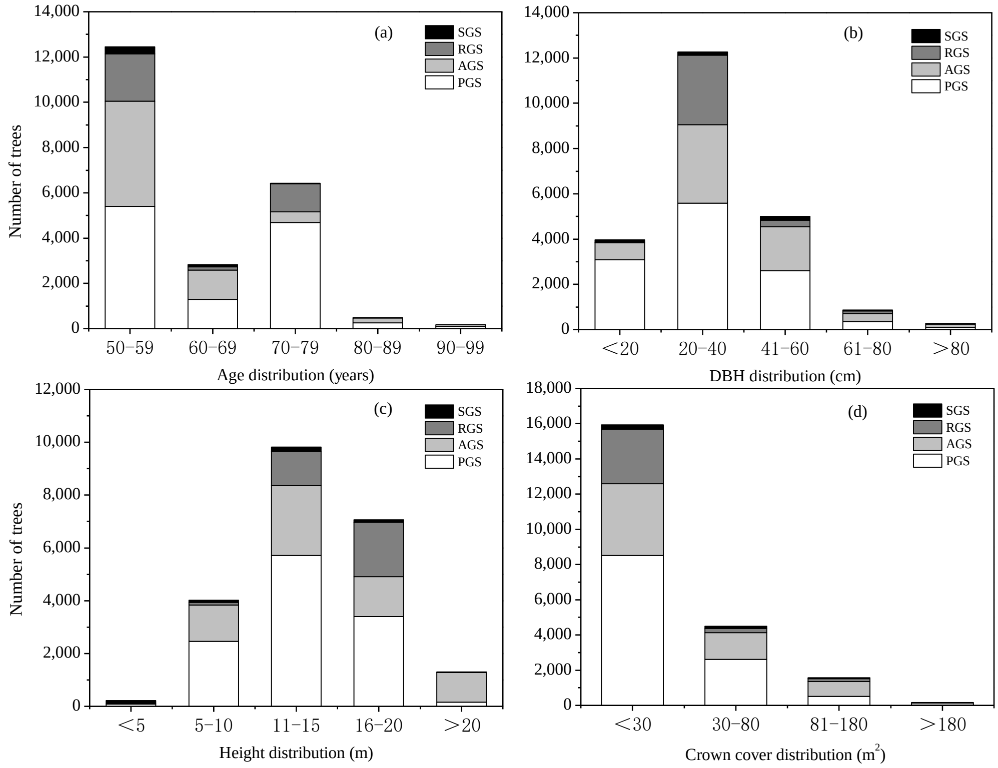


**Figure 1.** Age, DBH, height, and crown cover distribution of middle-aged trees. (**a**) Number of middle-aged trees in different age classes; (**b**) number of middle-aged trees in different DBH grades; (**c**) number of middle-aged trees in different height grades; (**d**) number of middle-aged trees in different crown cover grades. SGS, square green spaces; RGS, road green spaces; AGS, attached green spaces; PGS, park green spaces.

The distribution of middle-aged trees in different height grades showed that the number of trees at the height of 11–15 m was the largest, followed by the grade of 16–20 m, 5–10 m, and >20 m; however, the number of trees in the grade of <5 m was the lowest, which accounted for 43.95%, 31.62%, 17.65%, 5.81%, and 0.98%, respectively (Figure 1c). For the different types of green spaces, at the grades of 5–10 cm, 11–15 cm, and 16–20 cm, the number of trees all ranked as PGS > AGS > RGS > SGS, at the range of <5 m, which ranked as SGS > PGS > AGS > RGS. However, for the trees at the range of >20 m, the AGS had the highest number of trees, accounting for 86.13% of this grade, followed by the PGS, accounting for 12.63%, and the SGS only accounted for 0.08% of this grade's trees.

The distribution of middle-aged trees in different crown cover grades showed that trees distributed at the range of <30 m$^2$ had the highest number, followed by the grades of 30–80 m$^2$ and 81–180 m$^2$. The number of trees at the range of >180 m$^2$ was the lowest, which accounted for 72.37%, 20.44%, 7.14%, and 0.05%, respectively (Figure 1d). At the grades of <30 m$^2$ and 30–80 m$^2$, the number of trees was ranked as PGS > AGS > RGS > SGS, and at the range of 81–180 m$^2$ and >180 m$^2$, the number of trees was ranked as AGS > PGS > RGS > SGS.

### *3.3. Species Diversity Characteristics of Middle-Aged Trees among Different Types of Green Spaces and Different Age Classes*

The species richness and diversity characteristics of middle-aged trees in different types of green spaces varied greatly (Figure 2). For the mean value of SR and dMa, the

PGS was the highest and significantly higher than other types of green spaces ($p < 0.05$), but there was no significant difference among AGS, RGS, and SGS ($p > 0.05$). For the Shannon–Wiener index $H_e$, PGS also had the highest mean value of 1.79, followed by AGS, and RGS was the lowest, with a mean value of only 0.51. However, AGS had the highest value of 0.68 for $J_e$, followed by PGS, and RGS had the lowest value of only 0.26. Furthermore, the mean value of $H_e$ and $J_e$ in AGS and PGS was significantly higher than RGS ($p < 0.05$). These results indicate that the SR in PGS were richer and diverse and evenly distributed, but in RGS, they were poor and uneven.

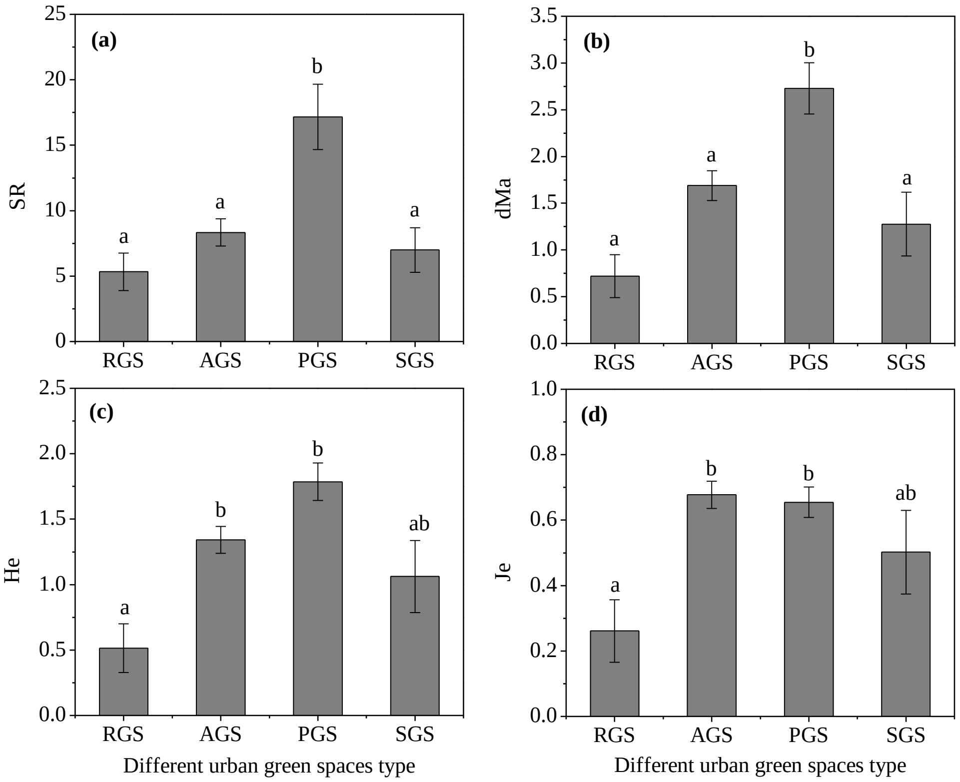


**Figure 2.** SR and diversity indexes of middle-aged trees among different types of green spaces in Changchun city. Note: Data in the figure are means ± standard errors; different lowercase letters indicate significant differences ($p < 0.05$). (**a**) SR, species richness; (**b**) dMa, Margalef richness index; (**c**) $H_e$, Shannon–Wiener index; (**d**) $J_e$, evenness index. RGS, road green spaces; AGS, attached green spaces; PGS, park green spaces; SGS, square green spaces.

The diversity characteristics of middle-aged trees among different age classes varied greatly (Figure 3). The SR of middle-aged trees decreased with an increase in age class. The value of SR in Age Class 50–59 years was 67 species and higher than in Age Class 90–99. However, Age Class 70–79 years had the lowest value of dMa, $H_e$, and $J_e$. The indexes of dMa, and $H_e$ had a similar trend in different age classes. They were highest in Age Class 50–59 years, followed by Age Class 60–69 years, Age Class 80–89 years, and Age Class 90–99 years. Age Class 80–89 years and Age Class 90–99 years had a lower value of SR, dMa, and $H_e$ but had a higher value of $J_e$ compared with other three age classes.

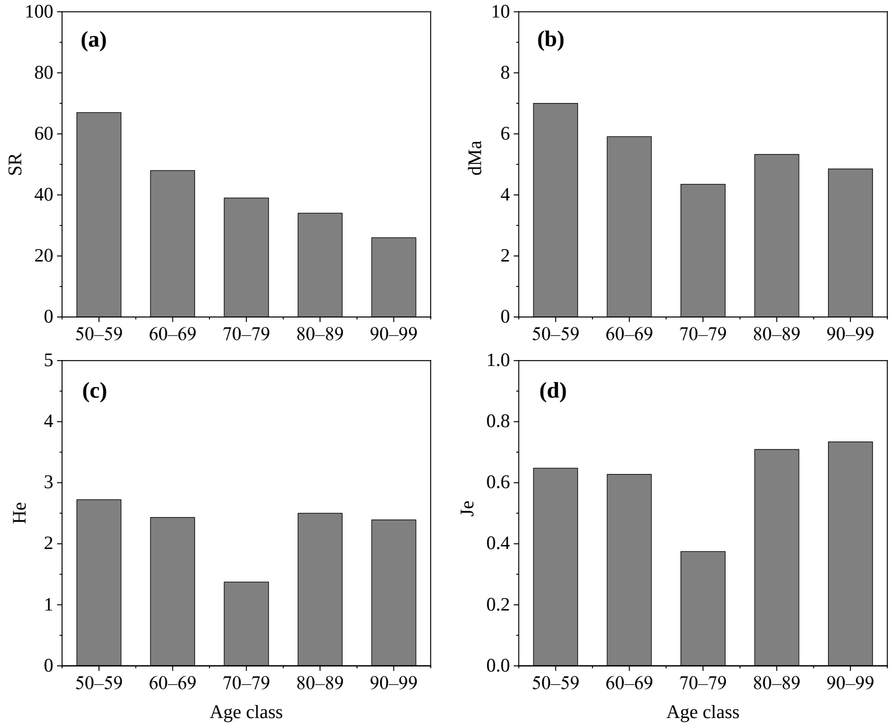


**Figure 3.** Diversity characteristics of middle-aged trees among different mean age classes in Changchun city. (**a**) SR, species richness; (**b**) dMa, Margalef richness index; (**c**) $H_e$, Shannon–Wiener index; (**d**) $J_e$, evenness index.

*3.4. PCA Analysis of Species Composition of Middle-Aged Trees among Different Types of Green Spaces and Different Age Classes*

PCA analysis of middle-aged tree species composition among the different types of green spaces showed that the species richness of PGS was the highest, followed by AGS, while SGS and RGS were relatively lower, with species richness of 57, 53, 22 and 19, respectively (Figure 4). For the type of AGS, the abundance of *Fra man*, *Abi hol*, *Sal mat*, *Phe amu*, *Arm sib*, *Mal bac*, *Lar gme*, *Qur mon*, *Pyr uss*, *Jug man*, and *Ace pic* was higher than in the other types of green spaces. Furthermore, *Pic jez*, *Ace neg*, *Pop uss*, *Sal mat tor*, *Cor con*, *Pin str, Syr ret*, *Til man*, *Kal sep*, *Mal asi*, *Pop can*, and *Xan sor* were the unique species. For the type of PGS, the abundance of *Lar olg* was the highest, followed by *Pin tab muk*, *Pin kor*, *Pic kor*, *Ulm pum*, *Abi hol*, *Maa amu*, *Sal mat*, *Til amu*, and *Pin syl mon.*, among the above species, except for the abundance of *Abi hol* and *Sal mat*, which were lower than in the type of AGS, the abundance of the other species was the highest in the type of PGS. In addition, the species of *Pin syl syl*, *Bet dah*, *Pte ste*, *Cra pin*, *Act arg*, *Hem dav*, *Jun rig*, *Ulm dav*, *Tax cus*, *Alm man*, *Cel bun*, *Pic wil*, *Ace man*, *Pop alb pyr*, and *Gin bil* was the unique species in the type of PGS. For the type of RGS, the abundance of the top eight species was *Lar olg, Pin tab muk, Pin syl mon, Bet pla, Sal mat, Pop pse Arm sib,* and *Euo maa, respectively.* Among them, *Pop pse and Bet pla* had a higher abundance in RGS than in the other types of green spaces, but the abundance of *Pin tab muk*, *Sal mat*, *Arm sib*, and *Pic kor* was lower than in the types of PGS and AGS. However, for the type of SGS, *Syr obl* and *Lon Maa* were the unique species, but the abundance of *Arm man*, *Pop xia*, and *Rha uss* was higher than in the other types of green spaces.

PCA analysis of middle-aged tree species composition among the different age classes showed that the species richness in Age Class 50–59 years was the highest, and the main species abundance was higher than that in other age classes, such as *Abi hol*, *Pin kor*, *Fra man*, *Maa amu*, *Til amu*, *Lar gme*, *Phe amu*, *Pop pse*, *Sal Mat*, and so on. In addition, *Syr obl*, *Ace man*, *Ace neg*, *Ace tri*, *Alm man*, *Amy dav*, *Cor con*, *Jun rig*, *Mag sie*, and *Pin syl syl* were the unique species in Age Class 50–59 years (Figure 5). In Age Class 60–69 years, the species abundance of *Arm sib*, *Que mon*, *Bet dah*, *Arm man*, and *Ulm dav* was higher than in the other age classes, and *Gin bil*, *Mal asi*, and *Pop alb pyr* were the unique species. In Age Class 70–79 years, the abundance of *Lar olg*, *Pin syl mon*, *Mal bac*, and *Bet pla* was higher than in other classes, and *Lon maa* was the unique species. In Age Class 80–89 and Age Class 90–99, the abundance of the main species was lower than in the other three age classes, and *Pop can* was the only unique species.

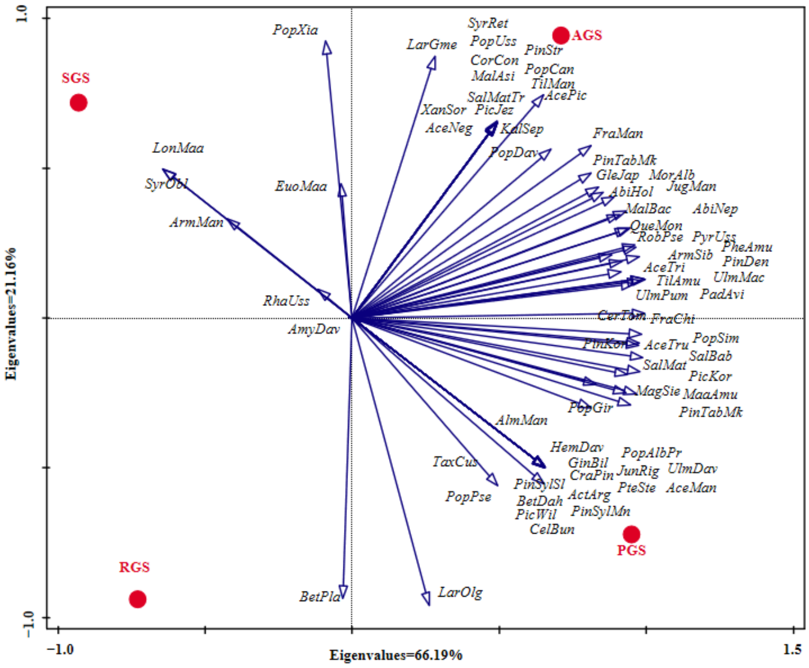


**Figure 4.** PCA analysis of the species composition among different types of green spaces. RGS, road green spaces; AGS, attached green spaces; PGS, park green spaces; SGS, square green spaces. For abbreviations of species names, refer to Table A1.

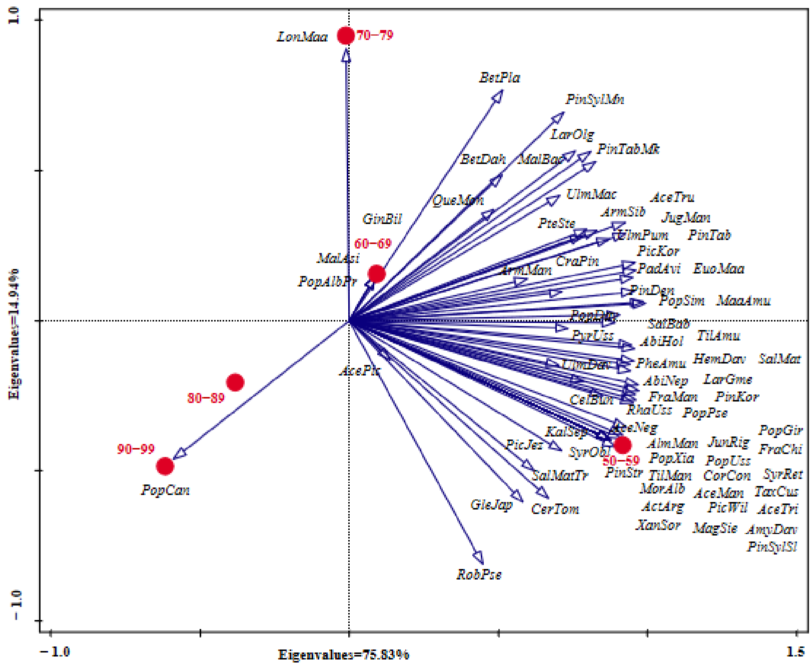


**Figure 5.** PCA analysis of the species composition among different age classes (years). For abbreviations of species names, refer to Table A1.

### *3.5. Species Dissimilarity of Middle-Aged Trees among Different Types of Green Spaces and Different Age Classes*

The spatial differentiation of middle-aged trees among the different types of urban green spaces was analyzed with SIMPER analysis (Figure 6). While the dissimilarity was 37.20% between AGS and PGS, between other types of green spaces, it was higher than 50%. This indicates that the species composition of AGS and PGS had a higher similarity. *Lar olg*, *Fra man*, *Pin kor*, *Phe amu*, *Sal mat*, and *Abi hol* were the main contributing species, which contributed to 43.01% of the total dissimilarity (Table 4). The highest dissimilarity was detected between RGS and SGS, with a value of up to 70.99%, followed by the dissimilarity between RGS and AGS, with a value of 64.17%. The dissimilarity between RGS and PGS was 52.05%. The highest dissimilarity between RGS and SGS can be attributed to the species of *Lar olg*, *Syr obl*, *Pop xia*, *Abi hol*, *Pin syl mon*, and *Pin tab muk*, contributing to 52.09% of the total dissimilarity. Between RGS and AGS, the species of *Lar olg*, *Fra man*, *Abi hol*, *Phe amu*, *Ulm pum*, and *Sal mat* contributed to 50.47% of the total dissimilarity. Furthermore, the dissimilarity between SGS and PGS and between SGS and AGS was at a moderate level, with a value of 52.29% and 58.86%, respectively.

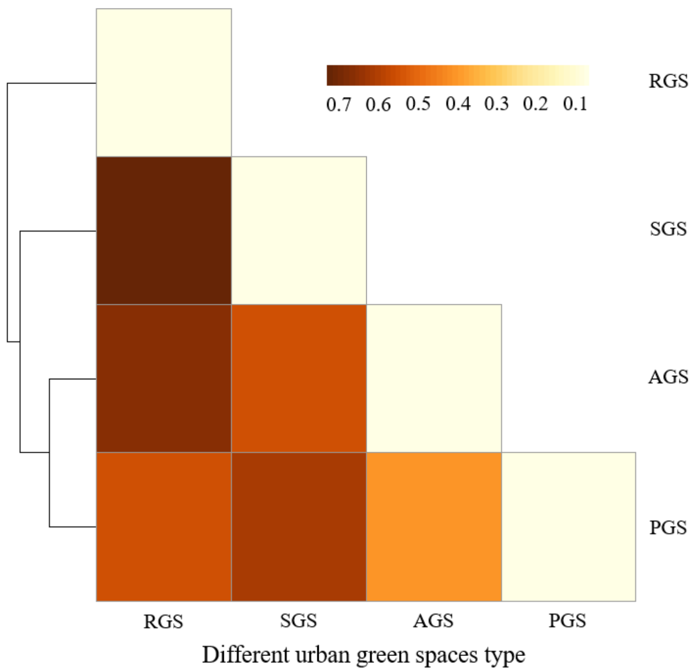


**Figure 6.** Dissimilarity among four types of green spaces based on species richness of middle-aged trees found by SIMPER analysis. RGS, road green spaces; SGS, square green spaces; AGS, attached green spaces; PGS, park green spaces.

**Table 4.** Main contributing species of middle-aged trees to the dissimilarity of different types of green spaces. RGS, road green spaces; SGS, square green spaces; AGS, attached green spaces; PGS, park green spaces. Values in parentheses represent the contribution of each species to the dissimilarity. For abbreviations of species names, refer to Table A1.

| Dissimilarity | PGS | AGS | RGS |
|---|---|---|---|
| AGS | *Lar olg* (13.36), *Fra man* (10.42), *Pin kor* (5.71), *Phe amu* (4.68), *Sal mat* (4.51) | | |
| RGS | *Lar olg* (9.60), *Pin kor* (8.45), *Ulm pum* (7.68), *Pic kor* (6.90), *Abi hol* (6.70) | *Lar olg* (17.62), *Fra man* (19.47), *Abi hol* (8.54), *Phe amu* (6.00), *Ulm pum* (5.03) | |
| SGS | *Syr obl* (10.75), *Lar olg* (8.22), *Pin kor* (6.82), *Pic kor* (5.52), *Pop xia* (5.46) | *Syr obl* (11.78), *Far man* (7.28), *Sal mat* (6.99), *Phe amu* (6.26), *Pop xia* (5.27) | *Lar olg* (17.31), *Syr obl* (12.08), *Pop xia* (6.44), *Abi hol* (6.20), *Pin tab muk* (5.08) |

The species dissimilarity of middle-aged trees between age classes was also analyzed by SIMPER analysis (Figure 7). The lowest dissimilarity was found between Age Class 60–69 years and Age Class 80–89 years (23.38%). The main contributing species were *Pin tab muk*, *Ace pic*, *Ulm pum, Abi hol,* and *Phe amu*, which contributed to 42.80% of the total dissimilarity (Table 5). In addition, the dissimilarity was 25.60% between Age Class 80–89 years and Age Class 90–99 years. However, the middle-aged tree species dissimilarity between Age Class 70–79 years and Age Class 90–99 years was the largest, which reached 59.23%, followed by the dissimilarity between Age Class 50–59 years and Age Class 90–99 years, and the dissimilarity between Age Class 70–79 years and Age Class 80–89 years, with a value of 54.41% and 50.39%, respectively. This indicates that the middle-aged tree species composition differed greatly between these age classes. The highest species dissimilarity (59.23%) of middle-aged trees between Age Class 70–79 years and Age Class 90–99 years can be attributed to the species of *Lar olg*, *Ulm pum*, *Sal mat*, *Pin syl mon*, and *Pin tab muk,* which contributed to 45.88% of the total dissimilarity.

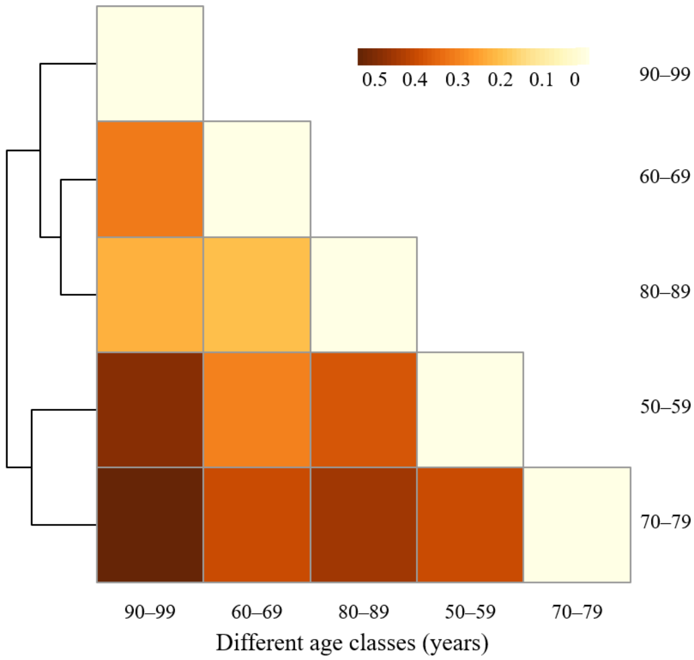


**Figure 7.** Dissimilarity among age classes based on species richness of middle-aged trees found by SIMPER analysis.

**Table 5.** Main contributing middle-aged tree species to the dissimilarity of different age classes. Values in parentheses represent the contribution of each species to the dissimilarity. For abbreviations of species names, refer to Table A1.

| Dissimilarity | Age Class 50–59 Years | Age Class 60–69 Years | Age Class 70–79 Years | Age Class 80–89 Years |
|---|---|---|---|---|
| Age Class 60–69 years | *Lar olg* (9.46), *Pin kor* (8.78), *Fra man* (7.28), *Pin tab muk* (6.83), *Ulm pum* (6.78) | | | |
| Age Class 70–79 years | *Lar olg* (11.59), *Abi hol* (9.57), *Pin kor* (8.80), *Fra man* (8.00), *Phe amu* (4.41) | *Lar olg* (21.16), *Ulm pum* (6.35), *Abi hol* (6.29), *Arm sib* (5.29), *Sal mat* (5.02) | | |
| Age Class 80–89 years | *Ulm pum* (9.84), *Lar olg* (8.12), *Pin kor* (7.14), *Abi hol* (6.83), *Fra man* (5.47) | *Pin tab muk* (13.25), *Ace pic* (8.46), *Ulm pum* (8.20), *Abi hol* (6.90), *Phe amu* (6.00) | *Lar olg* (19.22), *Ulm pum* (10.15), *Sal mat* (6.33), *Ace pic* (5.40), *Phe amu* (5.10) | |

**Table 5.** *Cont.*

| Dissimilarity | Age Class 50–59 Years | Age Class 60–69 Years | Age Class 70–79 Years | Age Class 80–89 Years |
|---|---|---|---|---|
| Age Class 90–99 years | *Ulm pum* (7.80), *Lar log* (7.76), *Pin kor* (6.60), *Abi hol* (6.14), *Sal mat* (4.37) | *Pin tab muk* (11.98), *Abi hol* (5.92), *Ulm pum* (5.61), *Sal mat* (5.27), *Mal bac* (5.16) | *Lar olg* (18.60), *Ulm pum* (8.98), *Sal mat* (7.69), *Pin syl mon* (5.47), *Pin tab muk* (5.15) | *Ace pic* (5.60), *Phe amu* (5.28), *Mal bac* (4.92), *Gle jap* (4.90), *Sal bab* (4.56) |

## 4. Discussion

### *4.1. General Species Composition of Middle-Aged Trees in Changchun*

Middle-aged trees are an important part of the urban ecosystem. A total of 72 species and 22,376 middle-aged trees were found in Changchun, which was much higher than the existing old trees (25 species and 773 trees) [44]. At the same time, the number of middle-aged trees in Changchun was higher than in Quzhou, Shanghai, and Yangzhou [18,22,25]. The richer species and larger number of middle-aged trees can be attributed to the fact that Changchun began to build an East Asian metropolis in the 1930s. Its urban planning work started earlier than most Chinese cities and took a leading position in the whole of Asia. Systematic green space construction not only left a large number of tree resources, but also retained a large number of urban green spaces for the city. Compared with old trees mostly scattered in the city, middle-aged trees exist as a community in urban green spaces and grow vigorously and strongly. In this study, the five middle-aged tree species with the highest importance value were *Pinus tabuliformis* var. *mukdensis*, *Lavix olgensis*, *Salix matsudana*, *Ulmus pumila*, and *Abies holophylla.* Among these five species, *Pinus tabuliformis* var. *mukdensi*, *Lavix olgensis*, and *Abies holophylla* were planted widely due to their excellent landscape properties and stronger resistance to pollution, drought, and poor soil, as well as remaining evergreen in all seasons. *Salix matsudana* and *Ulm pum* have strong resistance to cold and stressful urban environments, which enables them to grow and develop normally with human disturbance [44]. The above species are all the priority choice and key protection tree species for urban greening in the future.

Urban areas are hot spots for the intentional or unintentional introduction and naturalization of alien species [45]. The choice of plant species was a rather earnest preference for native species in the urban forests of Changchun [46]. In this study, the results of lower alien species richness and tree count were consistent with previous studies. Regional climate and human preferences for species influenced the introduction of alien species [46,47].

### *4.2. Species Composition, Diversity Attributes, and Differentiation of Middle-Aged Trees in Different Types of Green Spaces*

Higher spatial heterogeneity in cities leads to rich plant species diversity [48]. Previous studies have shown that species composition and diversity characteristics vary significantly among different urban forest types [46]. The combination of urban forest management systems and habitat conditions and their changes through time has engendered distinctive forest types in terms of ecological, amenity, and environmental functions [49]. In this study, middle-aged tree species composition and diversity among different types of green spaces also varied significantly. PGS had the highest number of middle-aged trees at different age classes, DBH, height, and crown cover grades, as well as having the highest SR, $H_e$, and $J_e$. This can be attributed to several reasons. On the one hand, the predominant species of *Pinus tabuliformis* var. *mukdensi* and *Lavix olgensis* of PGS have a long history of planting, as well as excellent adaptability to harsh urban environments. For example, *Pinus tabuliformis* var. *mukdensi* was widely planted in Changchun in the period of "Manchukuo" [50]. *Lavix olgensis* was planted in large quantities in the early years of the People's Republic of China. On the other hand, the conservation, protection, and management measures of PGS were professional and regular. PGS can provide adequate spaces and high-quality habitats for the long-term growth of a large number of middle-aged trees. Correspondingly, the effects between organisms and the environment are interactive. Middle-aged trees are tall and leafy. They not only provide stronger ecological services for human beings, but also play an important role in urban biodiversity protection and landmark plant landscape construction [51]. For RGS and SGS, the significantly lower number of middle-aged trees, SR, dMa, $H_e$, and $J_e$ is mainly due to the poor growth environment, monotonous species selection and simple community configuration, and lower level of protection and maintenance, as well as limited living spaces. Compared with other types of urban green spaces, tree planting and management in AGS are mainly decided by enterprises and institutions. Individual preference, land use spaces, management, and greening funding investment influenced the number of trees and the level of SR, $H_e$, and $J_e$ of middle-aged trees.

Species dissimilarities in different habitats were mainly contributed by dominant and common species [11]. In this study, species dissimilarity of middle-aged trees between AGS and PGS was the lowest. There were more species in common between these two types of urban green spaces, contributing to the lowest dissimilarity between AGS and PGS, but the number of the main contributing species of *Lar olg, Fra man, Pin kor, Phe amu, Sal mat,* and *Abi hol* varied greatly between AGS and PGS. Thus, strengthening the selection and protection of *Lar olg* and *Pin kor* for AGS and enhancing the management and protection of *Fra man, Phe amu, Sal mat*, and *Abi hol* for PGS is needed. The highest dissimilarity was detected between RGS and SGS, indicated by the higher similarity of species composition between RGS and SGS. This is mainly due to the wide application of coniferous species of *Lar olg*, *Pin syl mon*, and *Pin tab muk* in these two types of green spaces in history. Deciduous species of *Fra man*, *Abi hol*, *Phe amu*, *Ulm pum*, and *Sal mat* are suggested to be used in RGS and SGS in the future. Habitats of different types of green spaces vary greatly. Species differentiation by types of green spaces implies the need to preserve not only middle-aged trees, but more importantly their habitat and setting [11].

### *4.3. Species Composition, Diversity Attributes, and Differentiation of Middle-Aged Trees in Different Age Classes*

Understanding the characteristics of species composition and diversity attributes in different age classes was vital to maintaining the dynamic balance of biological populations in the urban ecosystem. Previous studies have shown that species differentiation is found among different administrative districts, which are closely related to the district construction history [11,44]. However, there are few studies on the characteristics of species composition and diversity of middle-aged trees in different tree age classes. In this study, we found the SR and number of middle-aged trees decreased with an increase in age classes. The total number of middle-aged trees in Age Class 80–89 years and Age Class 90–99 years accounted for 2.96%. This result indicates that the protection of middle-aged trees in Age Class 80–89 years and Age Class 90–99 years is urgently needed. Furthermore, Age Class 70–79 years had the second highest number of middle-aged trees but had the lowest dMa, $H_e$, and $J_e$, reflecting that species distribution is extremely uneven in this age class. The species diversity of $H_e$ and $J_e$ can be enhanced by increasing the protection of rare and unique species in different age classes. Planting rare and native tree species would be an effective way to mitigate the biotic homogenization of urban green spaces [52].

In this study, species dissimilarity of middle-aged trees between Age Class 60–69 years and Age Class 80–89 years was the lowest. The uneven distribution of *Pin tab muk*, *Ace pic*, *Ulm pum, Abi hol*, and *Phe amu* contributed more to the dissimilarity. For example, the abundance of *Pin tab muk*, *Ulm pum, Abi hol*, and *Phe amu* was much higher in Age Class 60–69 years than in Age Class 80–89 years, but the abundance of *Ace pic* was higher in Age Class 80–89 years than in Age Class 60–69 years. The second lowest dissimilarity between Age Class 80–89 years and Age Class 90–99 years indicates that the similarity of middle-aged tree species composition was higher between these age classes. It is urgent to protect and maintain the main contributing species of *Ace pic*, *Phe amu*, *Mal bac*, *Gle jap*, and *Sal bab* in these two age classes. These results also demonstrated that more attention should be paid to species selection and cultivation at multiple age classes during urban green space planning and community structure configuration.

## 5. Conclusions and Implications

The middle-aged tree species is richer in Changchun. A total of 72 species and 22,376 middle-aged trees were found in Changchun, which was much higher than the existing old trees. Great spatial differentiation of middle-aged trees existed among the different types of green spaces. Growth spaces, environment, and management measures were the main influencing factors. Decreasing the differentiation between types of green spaces, strengthening the selection and protection of *Lar olg* and *Pin kor* for AGS, and enhancing the selection and protection of *Fra man*, *Phe amu*, *Sal mat*, and *Abi hol* for PGS are urgently needed. Deciduous species of *Fra man*, *Abi hol*, *Phe amu*, *Ulm pum*, and *Sal mat* are suggested to be used in RGS and SGS. Middle-aged tree species diversity also varies greatly among different age classes. Protection of middle-aged trees in Age Class 80–89 years and Age Class 90–99 years is urgently needed. Furthermore, species distribution is extremely uneven in Age Class 70–79 years. Increasing the protection of rare and unique species is important to enhance $H_e$ and $J_e$ in Age Class 70–79 years. The selection and configuration of tree species at multiple age classes should be considered in plant community construction.

With rapid urbanization, the survival pressure of middle-aged trees is increasing. In order to better protect middle-aged trees, we suggest (1) to formulate protection and management measures for middle-aged trees, such as the improvement of soil, the application of fertilizer, the expansion of the tree pool, and the pruning of branches and leaves [44]; (2) to set up protection signs for trees in Age Class 80–89 years and Age Class 90–99 years; and (3) to establish a long-term dynamic monitoring platform to observe the growth, health, habitats, and changes of middle-aged trees. Monitoring data should include geographical location information (location, green space type, geographic coordinates), growth and structural attributes (DBH, tree height, crown width, tree age, growth status), environmental information (soil properties, human disturbance, land use change), and maintenance management information (watering, fertilization, pest control, rejuvenation measures).

**Author Contributions:** Y.Y., X.S., C.Z. and D.Z. lead the data collection. Z.W. and J.W. analyzed the data and drew the figures. The manuscript was written by Y.Y. The article was revised by D.Z. All authors have read and agreed to the published version of the manuscript.

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

## Appendix A

**Table A1.** Species botanical names and abbreviations of middle-aged trees in Changchun city.

| Species Name | Abbreviation | Species Name | Abbreviation |
|---|---|---|---|
| *Abies holophylla* Maxim. | *Abi hol* | *Phellodendron amurense* Rupr. | *Phe amu* |
| *Abies nephrolepis* (Trautv.) Maxim | *Abi nep* | *Picea jezoensis* | *Pic jez* |
| *Acer mandshuricum* Maxim. | *Ace man* | *Picea koraiensis* Nakai | *Pic kor* |
| *Acer negundo* L. | *Ace neg* | *Picea wilsonii* Mast. | *Pic wil* |
| *Acer pictum subsp. mono* (Maxim.) H. Ohashi | *Ace pic* | *Pinus densiflora* Sieb.et Zucc. | *Pin den* |
| *Acer triflorum* Kom. | *Ace tri* | *Pinus koraiensis* Siebold et Zuccarini | *Pin kor* |
| *Acer truncatum* Bunge | *Ace tru* | *Pinus strobus* L. | *Pin str* |
| *Actinidia arguta* (Sieb. et Zucc.) Planch. ex Miq. | *Act arg* | *Pinus sylvestris* var. *mongolica* Litv. | *Pin syl mon* |
| *Alnus mandshurica* (Callier) Hand.-Mazz. | *Alm man* | *Pinus sylvestris* var. *sylvestriformis* (Takenouchi) Cheng et C. D. Chu | *Pin syl syl* |
| *Amygdalus davidiana* (Carr.) C. de Vos | *Amy dav* | *Pinus tabulaeformis* Carriere | *Pin tab* |

**Table A1.** *Cont.*

| Species Name | Abbreviation | Species Name | Abbreviation |
|---|---|---|---|
| *Armeniaca mandshurica* (Maxim.) Skv. | *Arm man* | *Pinus tabuliformis* var. *mukdensis* (Uyeki ex Nakai) Uyeki | *Pin tab muk* |
| *Armeniaca sibirica* (L.) Lam. | *Arm sib* | *Populus* × *canadensis* Moench | *Pop can* |
| *Betula dahurica* Pall. | *Bet dah* | *Populus* × *xiaohei* T. S. Hwang et Liang | *Pop xia* |
| *Betula platyphylla* Suk. | *Bet pla* | *Populus alba* var. *pyramidalis* Bunge | *Pop alb pyr* |
| *Celtis bungeana* Bl. | *Cel bun* | *Populus davidiana* Dode | *Pop dav* |
| *Cerasus tomentosa* (Thunb.) Wall | *Cer tom* | *Populus girinensis* Skv. | *Pop gir* |
| *Cornus controversa* Hemsl. | *Cor con* | *Populus pseudo simonii* Kitagawa | *Pop pse* |
| *Crataegus pinnatifida* Bge. | *Cra pin* | *Populus simonii* Carr. | *Pop sim* |
| *Euonymus maackii* Rupr. | *Euo maa* | *Populus ussuriensis* Kom. | *Pop uss* |
| *Fraxinus chinensis subsp. rhynchophylla* (Hance) E. Murray | *Fra chi* | *Pterocarya stenoptera* C. DC. | *Pte ste* |
| *Fraxinus mandshurica* Rupr. | *Fra man* | *Pyrus ussuriensis* Maxim. | *Pyr uss* |
| *Ginkgo biloba* L. | *Gin bil* | *Quercus mongolica* Fischer ex Ledebour | *Que mon* |
| *Gleditsia japonica* Miq. | *Gle jap* | *Rhamnus ussuriensis* J. Vass. | *Rha uss* |
| *Hemiptelea davidii* (Hance) Planch. | *Hem dav* | *Robinia pseudoacacia* L. | *Rob pse* |
| *Juglans mandshurica* Maxim. | *Jug man* | *Salix babylonica* L. | *Sal bab* |
| *Juniperus rigida* Sieb. et Zucc. | *Jun rig* | *Salix matsudana f. tortuosa* (Vilm.) Rehd. | *Sal mat tor* |
| *Kalopanax septemlobus* (Thunb.) Koidz | *Kal sep* | *Salix matsudana* Koidz | *Sal mat* |
| *Larix gmelinii* (Rupr.) Kuzen. | *Lar gme* | *Syringa oblata* Lindl. | *Syr obl* |
| *Lavix olgensis* Henry | *Lar olg* | *Syringa reticulata subsp. amurensis* (Ruprecht) P. S. Green & M. C. Chang | *Syr ret* |
| *Lonicera maackii* (Rupr.) Maxim. | *Lon maa* | *Taxus cuspidata* Sieb. et Zucc | *Tax cus* |
| *Maackia amurensis* Rupr. et Maxim | *Maa amu* | *Tilia amurensis* Rupr. | *Til amu* |
| *Magnolia sieboldii* | *Mag sie* | *Tilia mandshurica* Rupr. et Maxim. | *Til man* |
| *Malus asiatica* Nakai | *Mal asi* | *Ulmus davidiana* var. *japonica* (Rehd.) Nakai | *Ulm dav* |
| *Malus baccata* (L.) Borkh | *Mal bac* | *Ulmus macrocarpa* Hance | *Ulm mac* |
| *Morus alba* L. | *Mor alb* | *Ulmus pumila* L. | *Ulm pum* |
| *Padus avium* Miller | *Pad avi* | *Xanthoceras sorbifolium* Bunge | *Xan sor* |

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