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Determining Large Trees and Population Structures of Typical Tree Species in Northeast China

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Abstract

Specialized research on large trees in Northeast China is rare. To strengthen the understanding of local large trees, a survey of 4055 tree individuals from 75 plots in southeastern Jilin Province was conducted. The individual number and species composition of large trees in the community, as well as large individual standards in diameter at breast height (DBH) and population structures of typical tree species, were analyzed. By setting a DBH $\geq$ 50 cm as the threshold, 155 individuals across all the recorded trees were determined as large trees in the community, and 32.9% (51/155) of them were national second-class protected plant species in China. By setting the top 5% in DBH of a certain tree species as the threshold of large individuals of that tree species, the large individual criteria of six typical tree species were determined. The proportion of basal area of large trees to all trees was 30.4%, and the mean proportion of basal area of large individuals across the six typical tree species was 23.9% ($\pm$4.0%). As for the population characteristics, *Abies nephrolepis* and *Picea jezoensis* had large population sizes but relatively thin individuals, *Tilia amurensis* and *Pinus koraiensis* had small population sizes but relatively thick individuals, while *Betula costata* and *Larix olgensis* had medium population sizes and medium-sized individuals.

Keywords: diameter class structure; protected plant; species composition; forest protection

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Academic Editor: Michael Wink

Received: 27 June 2025
Revised: 15 July 2025
Accepted: 16 July 2025
Published: 18 July 2025

Citation: Yang, Y.; Jia, Z.; Ge, S.; Li, Y.; Kang, D.; Li, J. Determining Large Trees and Population Structures of Typical Tree Species in Northeast China. *Diversity* **2025**, *17*, 491. https://doi.org/10.3390/d17070491

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1. Introduction

Forests can be understood as biological communities or ecosystems dominated by perennial woody plants [1]. By the end of 2023, China's forest coverage had exceeded 25%, and the forest stock volume had exceeded 20 billion m^3 [2]. Various types of forests play vital roles in biodiversity conservation and ecological functions [3]. Through scientific research, enhancing the knowledge and understanding of forest communities is of great importance for forest conservation.

As an important forest distribution area in China, the forests in Northeast China have attracted a large number of community ecology studies, such as research on species composition [4,5], interspecific relationships [6,7], community structure [8,9], community succession [10,11], community stability [12,13], and response to climate [14,15]. These studies have enriched the understanding of local forests and provide important information for local forest protection.

However, many unresolved fundamental questions remain. For example, as an important component of forest communities, large trees play various ecological roles such as in

aspects of biomass, diversity, and function [16–19]. Although there have been many studies on large trees in China [20–22] and abroad [23–25], specialized studies on large trees in Northeast China have rarely been reported [26]. To our knowledge, the composition of species, number, and distribution of large trees in local forest communities, as well as size thresholds for large individuals of different tree species, remain unclear. Therefore, it is necessary to carry out relevant studies to fill these knowledge gaps.

Although a lot of relevant studies have been conducted, the method for determining large trees is not unique, and it is necessary to detect widely applicable methods to describe and analyze the characteristics of large trees. For example, individuals with a diameter at breast height (DBH) not lower than a given value (i.e., 60 cm, 70 cm) or within the top proportion (i.e., 1%, 5%) of DBH can be defined as large trees [16,18]. These two research approaches have been widely recognized and adopted, and it is feasible to combine them to describe the large trees in a specific community, as well as large individuals across different tree species.

To investigate the large tree characteristics and population structure of typical tree species in Northeast China, a survey of tree individuals in forest communities of Jilin Province, China was conducted. The objectives were to (1) analyze the species composition and individual number of large trees in these communities, (2) determine size thresholds for large individuals of local typical tree species, (3) quantify the contribution of large trees/individuals to the community/species in terms of basal area, and (4) describe the population structures of typical tree species. By integrating these characteristics, this study aimed to provide a targeted protection strategy for local forests.

2. Methods

2.1. Data Collection

Northeast China is an important natural forest region in China. As an important part of this area, Jilin Province has abundant forest resources, with a forest coverage rate of 45.42% [27]. Given that forests in Jilin are primarily concentrated in its southeastern region [3], this study focused on forest communities in southeastern Jilin Province.

The study area involves three adjacent counties of Antu, Fusong, and Changbai, and they all belong to Jilin Province. Antu County is located in the eastern part of Jilin Province, with an area of 7444 km^2. The annual average temperature is 2.2 °C in the south and 3.6 °C in the north, and the annual average precipitation is 670 mm in the south and 595 mm in the north [28]. Fusong County is located in the southeastern part of Jilin Province, with an area of 6159 km^2. The annual average temperature is 4 °C, and the annual average precipitation is 800 mm [29]. Changbai County is located in the southeastern part of Jilin Province, with an area of 2506 km^2. The annual average temperature is 2 °C, and the annual average precipitation is 691 mm [30].

To investigate large trees and populations of typical tree species in southeastern Jilin Province, a total of 75 natural forest plots were established and surveyed (Figure S1; Table S1). To ensure spatial independence, a minimum distance of 4 km was maintained between any two plots. Each plot was set at 600 m^2 in size. Within each plot, all tree individuals with a DBH $\geq$ 5 cm were identified, and their species name, DBH, and living status (alive or dead) were recorded. Dead trees were excluded from the analysis. Additionally, the location information (latitude, longitude, and elevation) of each plot was documented.

2.2. Data Analysis

2.2.1. Analysis on Large Trees in the Community

To clarify the basic information of trees, this study counted the total number of trees, analyzed the composition of tree species, and calculated the individual number and pro-

portion of each tree species. This study also examined the species and individual numbers of protected plants. To identify if there were protected plants, this study checked all tree species according to the List of National Key Protected Wild Plants [31] and determined the species names, protection levels, and individual numbers of the protected tree species in detail.

To describe the large tree characteristics in the community, this study extracted all large tree individuals from each plot and summarized them together. The criteria for determining large trees within forest communities lack standardization [18]. Given the rarity of tree individuals exceeding 50 cm DBH in the study area, large trees were defined as those with DBH $\geq$ 50 cm to facilitate research. The mean value and DBH range of large trees were determined. Additionally, the basic data such as species composition, individual number, and proportion of large trees were counted and calculated. Specifically, this study also analyzed the basic information of protected plants among the identified large tree individuals, such as species name, individual number, and proportion.

To quantify the contribution of large trees to the community in terms of basal area, this study calculated the proportion of the basal area of large trees to all trees. To provide a detailed description, 75 plots were divided into two categories, large tree-present and non-large tree plots. For each large tree-present plot, the proportion of basal area of large trees to all trees was calculated. For all large tree-present plots, the mean proportion of the basal area of large trees and its range were determined.

2.2.2. Analysis of Large Individuals of Typical Tree Species

To explore the large individual standards of typical tree species, all tree individuals in 75 plots were combined for analysis. This study defined the typical tree species as the species with a relative basal area (RBA) value > 0.05 and an individual number > 100. The RBA was calculated by dividing the basal area of a tree species by the total basal area of all trees [32].

For each determined typical tree species, all individuals from the 75 plots were first extracted by species and ranked by DBH. The top 5% of individuals by DBH for a certain species were then selected as large individuals of that tree species. The minimum DBH value among these large individuals was established as the size threshold for large individuals of that tree species.

To quantify the contribution of large individuals across species, the proportion of the basal area of large individuals in each typical tree species was calculated. The mean proportion of the basal area of large individuals and its range were then determined for the typical tree species.

2.2.3. Analysis on Population Composition of Typical Tree Species

Age structure reflects population composition [33,34]. To analyze the diameter class structure of typical tree species, this study created the individual number–DBH class diagram of each tree species. First, the DBH class was determined by setting 5.0 cm as the starting point and each 5 cm as a DBH class range; a total of 16 DBH classes were established. Then, the individual number in each DBH class was counted by species. Finally, the individual numbers of each species were displayed in the order of increasing DBH class. For the obtained individual number–DBH class diagrams, this study compared the population composition characteristics of the typical tree species, such as individual number distribution and the maximum DBH class.

To visualize the population composition in detail, this study created the DBH–DBH order scatter diagram for each typical tree species (with DBH on the vertical axis and DBH in ascending order on the horizontal axis). To explore if the population composition of different tree species had distinctive or shared characteristics, this study compared the

individual number and mean size using the calculation results and visual diagram. For the comparison of DBH among different tree species, this study used either analysis of variance (ANOVA) or the Kruskal–Wallis H test for analysis [35]. For multiple comparisons, this study used either Bonferroni or the Games–Howell tests for analysis [36,37]. The significance level was set as $p < 0.05$.

3. Results

3.1. Species Composition

A total of 4055 tree individuals belonging to 35 species were surveyed in the 75 plots. The top five species in individual number were *Abies nephrolepis* (Trautvetter ex Maximowicz) (AN), *Picea jezoensis* (Siebold and Zuccarini) Carrière (PJ), *Acer ukurunduense* (Trautvetter and C.A. Meyer) (AU), *Betula costata* (Trautvetter) (BC), and *Larix olgensis* (A. Henry) (LO); they accounted for 69.6% (2821/4055) of the total number of tree individuals.

Among all surveyed trees, 316 individuals were national second-class protected plant species in China. They were composed of *Tilia amurensis* (Ruprecht) (TA) (155 individuals), *Pinus koraiensis* (Siebold and Zuccarini) (PK) (118 individuals), *Fraxinus mandschurica* (Ruprecht) (FM) (29 individuals), *Phellodendron amurense* (Ruprecht) (PA) (seven individuals), and *Pinus sylvestris* var. *sylvestriformis* (Takenouchi) W.C. Cheng and C.D. Chu (PS) (seven individuals), accounting for 7.8% (316/4055) of the total number of tree individuals.

3.2. Large Tree Number, Species Composition, and Contribution to Basal Area in the Community

A total of 155 tree individuals with a DBH $\geq$ 50 cm belonging to 12 species were determined as large trees in the community, accounting for 3.8% (155/4055) of the total number of tree individuals. The DBH of these large trees ranged from 50.0 cm to 101.7 cm, with a mean size of 61.6 cm. As for the composition, seven species had an individual number > 10, while the individual number of the remaining five species was <5 (Figure 1). Among these large trees, 51 individuals from four species were national second-class protected plant species in China, namely PK (27 individuals), TA (21 individuals), FM (2 individuals), and PS (1 individual) (Figure 1).

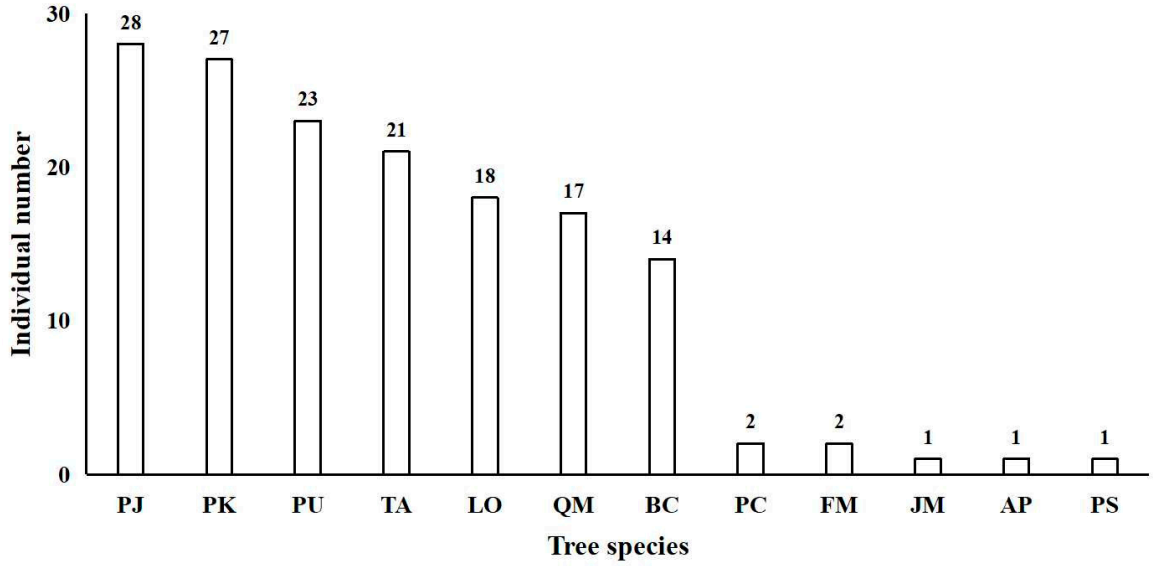


Figure 1. Species composition and individual number of large trees (diameter at breast height (DBH) $\geq$ 50.0 cm) (PJ: *Picea jezoensis*; PK: *Pinus koraiensis*; PU: *Populus ussuriensis* (Komarov); TA: *Tilia amurensis*; LO: *Larix olgensis*; QM: *Quercus mongolica* (Fischer ex Ledebour); BC: *Betula costata*; PC: *Picea koraiensis* (Nakai); FM: *Fraxinus mandschurica*; JM: *Juglans mandshurica* (Maximowicz); AP: *Acer pictum* (Thunberg); PS: *Pinus sylvestris* var. *sylvestriformis*).

The total basal area of 155 large trees accounted for 30.4% (475,489.06 cm^2/1,565,937.05 cm^2) of all trees. All plots were divided into two categories of large tree-present (52 plots) and non-large tree (23 plots) plots. As for the large tree-present plots, the proportion of basal area of large trees to all trees in each plot ranged from 7.8% to 75.8%, with a mean (standard deviation) proportion of 36.6% (±19.7%). Specifically, 30.8% (16/52) of the large tree-present plots had a proportion > 50%.

3.3. Large Individual Criteria and Contribution to Basal Area of Typical Tree Species

The RBA value of eight species was >0.05. They were PJ (RBA = 0.199), AN (RBA = 0.138), LO (RBA = 0.103), BC (RBA = 0.097), TA (RBA = 0.094), PK (RBA = 0.081), PU (RBA = 0.077), and QM (RBA = 0.053). The individual number of PU and QM was <100, and they were excluded from further analysis. Thus, six species of PJ, AN, LO, BC, TA, and PK were determined as local typical tree species.

Based on the rule of top 5% in DBH of each typical tree species, the large individual criteria for the six typical tree species were determined as follows: DBH ≥ 47.0 cm for PJ, DBH ≥ 31.2 cm for AN, DBH ≥ 54.8 cm for LO, DBH ≥ 49.8 cm for BC, DBH ≥ 67.8 cm for TA, and DBH ≥ 71.5 cm for PK (Figure 2). The proportion of basal area of large individuals in the six typical tree species ranged from 18.4% to 28.9% (Figure 3), with a mean (standard deviation) proportion of 23.9% (±4.0%).

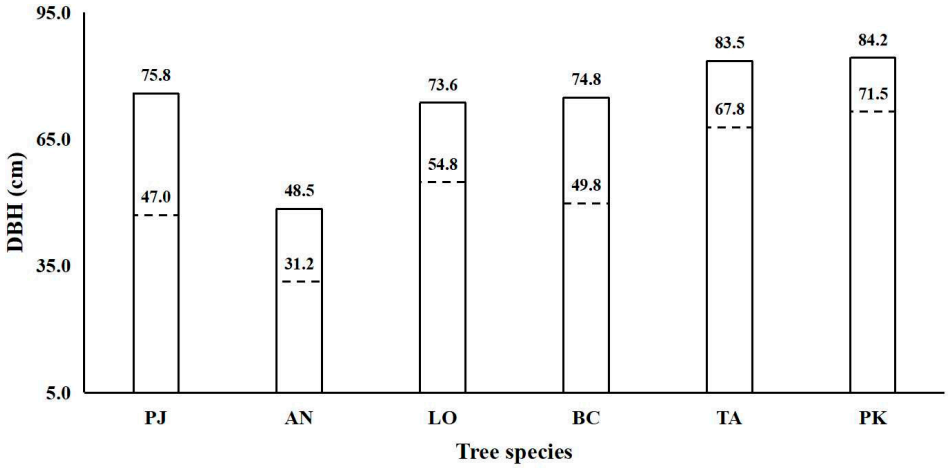


Figure 2. Diameter at breast height (DBH) ranges and large individual criteria for six tree species (PJ: *Picea jezoensis*; AN: *Abies nephrolepis*; LO: *Larix olgensis*; BC: *Betula costata*; TA: *Tilia amurensis*; PK: *Pinus koraiensis*).

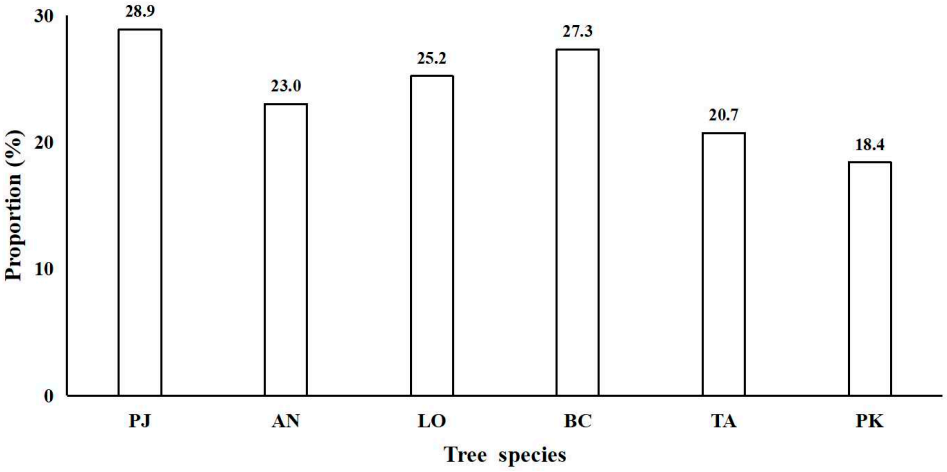


Figure 3. Proportions of the basal area of large individuals from six tree species (PJ: *Picea jezoensis*; AN: *Abies nephrolepis*; LO: *Larix olgensis*; BC: *Betula costata*; TA: *Tilia amurensis*; PK: *Pinus koraiensis*).

3.4. Diameter Class Structures of Typical Tree Species

The six typical tree species exhibited different population characteristics. For the population size, two species (AN and PJ) had >700 individuals, two species (BC and LO) had approximately 300 individuals, and two protected species (TA and PK) had <200 individuals (Figure 4). Viewed from the distribution of individuals in different DBH classes, in the class of 5 cm $\leq$ DBH < 10 cm, two species (AN and PJ) had >200 individuals, two species (BC and LO) had approximately 100 individuals, and two protected species (TA and PK) had <50 individuals (Figure 5). For the maximum diameter class, one species (AN) was <50 cm, three species (PJ, LO, and BC) were <80 cm, and two protected species (TA and PK) were >80 cm (Figure 5). As for the individual number change from low to high DBH classes, two species (AN and PJ) varied greatly, two species (BC and LO) varied moderately, and two protected species (TA and PK) varied slightly (Figure 5).

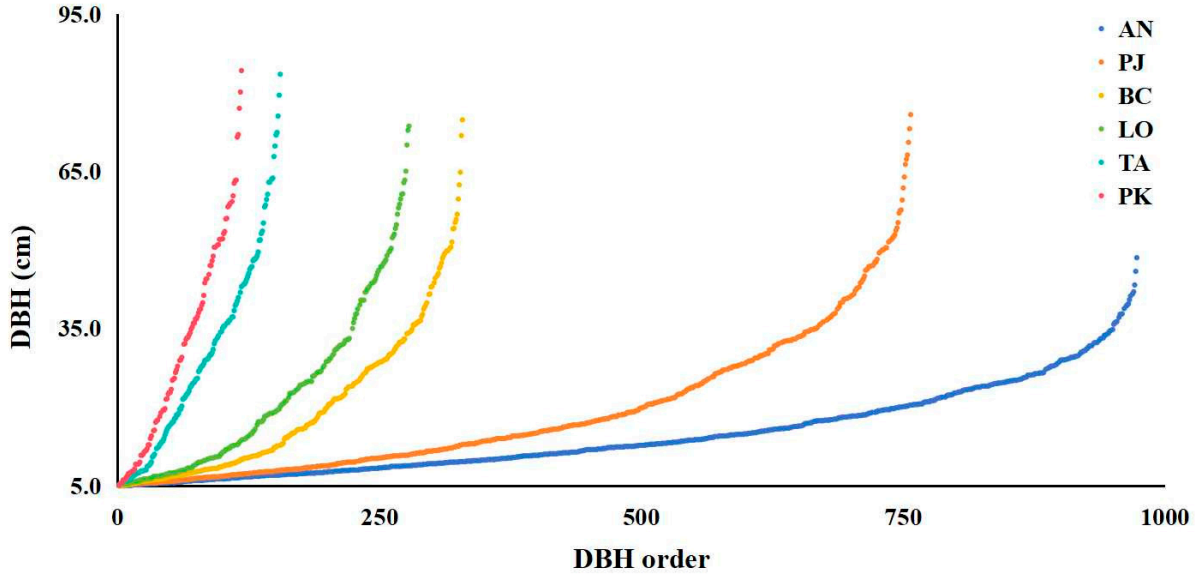


Figure 4. Diameter at breast height (DBH) and order of six tree species (AN: *Abies nephrolepis*; PJ: *Picea jezoensis*; BC: *Betula costata*; LO: *Larix olgensis*; TA: *Tilia amurensis*; PK: *Pinus koraiensis*).

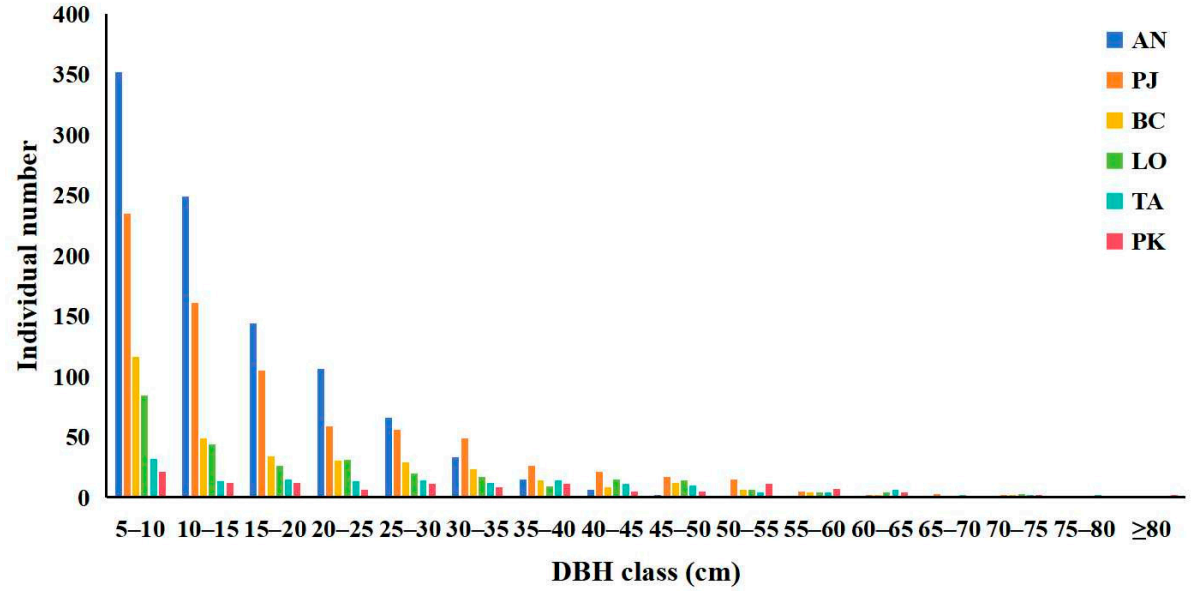


Figure 5. Diameter class distribution of six tree species (AN: *Abies nephrolepis*; PJ: *Picea jezoensis*; BC: *Betula costata*; LO: *Larix olgensis*; TA: *Tilia amurensis*; PK: *Pinus koraiensis*).

The mean DBH differed significantly among the six tree species (Kruskal–Wallis H test, $\chi^2 = 152.282$, $p < 0.01$). The mean size of AN was 14.7 cm (n = 973), which was significantly lower than those of the other five tree species ($p < 0.05$). The mean size of BC was 19.6 cm (n = 329), which had no significant difference from those of PJ (mean DBH = 18.8 cm, n = 757) and LO (mean DBH = 22.0 cm, n = 278), while the mean size of PJ and LO differed significantly ($p < 0.05$). Furthermore, the mean size of TA (mean DBH = 29.2 cm, n = 155) and PK (mean DBH = 31.3 cm, n = 118) had no significant difference ($p > 0.05$) (Table 1).

Table 1. Multiple comparisons of diameter at breast height (mean difference and significance level) among six tree species (using Games–Howell method) (AN: *Abies nephrolepis*; PJ: *Picea jezoensis*; BC: *Betula costata*; LO: *Larix olgensis*; TA: *Tilia amurensis*; PK: *Pinus koraiensis*).

Tree Species	PJ	BC	LO	TA	PK
AN	−4.0 (0.000)	−4.8 (0.000)	−7.3 (0.000)	−14.5 (0.000)	−16.6 (0.000)
PJ		−0.8 (0.951)	−3.3 (0.027)	−10.4 (0.000)	−12.6 (0.000)
BC			−2.5 (0.348)	−9.6 (0.000)	−11.8 (0.000)
LO				−7.2 (0.001)	−9.3 (0.000)
TA					−2.1 (0.947)

In general, AN and PJ had large population sizes but relatively thin individuals, with abundant small-sized individuals. In contrast, TA and PK had small population sizes but relatively thick individuals; the small-sized individuals were scarce. Meanwhile, BC and LO had medium population sizes and medium-sized individuals, with moderately abundant small-sized individuals.

4. Discussion

4.1. Large Tree Characteristics and Large Individual Criteria

Species composition is an important characteristic in forest communities [33,34]. A total of 4055 tree individuals from southeastern Jilin Province were surveyed and recorded. The results demonstrated that the five most abundant species collectively represented 69.6% of total tree individuals, aligning with prior studies identifying species such as AN, PJ, AU, BC, and LO as important species [38–40]. Notably, 7.8% of recorded individuals from five species corresponded to protected plant species in China. Within this protected plant list, TA and PK dominated disproportionately, constituting 86.4% of individuals, highlighting their prominence among protected plants in amount. It is of great significance to protect these protected plants for local forest conservation.

Although a large number of ecological studies on the forests in Northeast China have been conducted, few studies have focused on the large trees [26]. This study, for the first time, revealed the composition of large trees in the study area, providing basic data for understanding local forests. This study analyzed >4000 individuals from 35 tree species, including more than 300 individuals from five protected tree species, covering a wide range of tree species and carrying a sufficient sample size.

Using a DBH $\geq$ 50 cm threshold, 155 individuals from 12 tree species were determined as large trees in the community, accounting for <5% of the total sample size. There are scarce amounts of resources in the study area, necessitating heightened protection efforts. More importantly, one-third of these species were protected, such as PK, TA, FM, and PS, demanding greater attention and specific protective measures.

Large trees play important ecological roles in various aspects [18,41,42], such as basal area [43,44], carbon stock [45,46], and habitat function [44,47]. By calculating the proportion of basal area contributed by large trees, this study found that they constituted <5% of the total individuals but contributed disproportionately to 30.4% of the total basal area. In

plots containing large trees, they accounted for an average of 36.6% of basal area per plot. Notably, in 30% of plots with large trees, large trees accounted for >50% of the basal area, underscoring their pivotal role in forest community structure and composition. Several previous studies have revealed the contribution of large trees in biomass [17,48–51]. This study quantified their contribution to basal area, enhancing understanding from additional perspectives.

Biological characters varied among plant species, necessitating the development of different large tree standards for different species. This study proposed, for the first time, large individual standards of the six typical tree species, enhancing the understanding of the typical tree growth status in this area. Although diameter class standards and results differ across studies, individuals from different tree species generally exhibit the following characteristics: PK and TA have relatively few individuals with a DBH > 65 cm [52–58]; PJ, BC, and LO have relatively few individuals with a DBH > 50 cm [55,59–63]; and AN has relatively few individuals with a DBH > 30 cm [55,61,63,64]. Therefore, the proposed large individual standards for these six typical tree species are reasonable and provide an important basis for protecting local tree species and forests. Furthermore, while large individuals constituted only 5% of the population for each species, they contributed a mean of 23.9% to the basal area. This demonstrated that large individuals, though few in number, occupied a considerable proportion of the basal area and played a disproportionate role in forests at species level.

4.2. Population Structure and Forest Protection

Composition and structure are the fundamental characteristics of a population [1]. For different tree species growing in the same region, understanding how they establish their dominance within the community represents an important question. Population ecology constitutes an important topic in the ecological research on the six tree species [59,60,65–68]. Research within this field includes many studies on the population composition and structure of the two protected tree species, PK and TA [52,54,57,58,69]. Similarly, several corresponding research studies exist on the other four tree species (PJ, AN, BC, and LO) [55,59,61–63,70]. These studies are important for understanding the survival status of these tree species' populations. However, due to variations in location and research methods, conducting a unified analysis is challenging.

This study used a unified research standard to analyze six typical tree species within the same region, enabling the direct comparison of the population characteristics of different tree species and revealing their population strategies. Based on the population size and basal diameter of the six tree species in southeastern Jilin Province, three kinds of population types were identified and summarized. For example, two species (PK and TA) had fewer but thicker individuals; they may have established dominance through large diameter. In contrast, two species (PJ and AN) had more but thinner individuals; their large population size may have contributed to their establishment of dominance. Unlike the previous two population types above, two species (LO and BC) had moderate individual numbers and diameters; the contribution of individual number and diameter to dominance appeared more balanced. The six tree species exhibited different population characteristics, particularly regarding individual number and diameter. These results provide important information for understanding the pathways by which different species establish dominance in communities. Notably, both PK and TA are protected plant species with small population sizes and few individual numbers in each diameter class. It could be predicted that, if individuals of these two tree species were destroyed, they would face a high risk of extinction due to their small population size and lack of regeneration reserves. Therefore,

conservation efforts for the protected tree species such as PK and TA should not focus solely on large individuals but must comprehensively consider the entire population.

Based on the composition of large trees and populations of typical tree species, this study proposed the following forest conservation strategies. For protected plants such as TA and PK, population size and individual numbers in each diameter class were small, with particularly insufficient numbers in the small diameter class. Therefore, the entire population, including all individuals regardless of size, should be prioritized for protection. Large trees in the community and large individuals of each species obviously contributed to basal area despite their low abundance; thus, their survival status requires greater attention. Furthermore, for individuals approaching large tree or large individual size range, growing monitoring should be implemented proactively.

4.3. Limitations and Research Needs

This study analyzed large trees and population compositions of local typical tree species, but there are many limitations that need to be disclosed. First, this study assumed a positive relationship between size and age of tree individuals and used DBH to define and analyze the large trees and population structure. However, tree diameter does not necessarily accurately reflect age [71]. More accurate methods for determining the age of trees, such as counting annual rings or sampling tree cores [72], should be considered to provide refined information. Second, the data used in this study were not up-to-date data and therefore failed to reflect the latest status of local forests. Data updating is needed to reveal the current status. Third, this study was based on 75 plots from three counties. The sample size was sufficient, but including more plots from wider forest areas would facilitate more robust conclusions. Fourth, this study performed a static analysis based on a single survey, preventing them from gaining insights into the dynamics of large trees and populations. Long-term repeated surveys based on fixed plots are needed to provide relevant information. Fifth, this study described the performance characteristics of large trees at community and species levels. However, it did not address many factors affecting the tree growth and species composition, such as climate [14,73], terrain [74,75], and disturbance [7,39]. Future studies involving these factors should explore the deriving forces shaping these characteristics. Furthermore, further research such as micro-habitat assessments and ecosystem service provision should be considered.

5. Conclusions

Large trees play important ecological roles in various aspects. However, specialized research on large trees in Northeast China is rare, which limits the understanding of the local large trees. To fill this knowledge gap, this study described large tree characteristics and population structures of typical tree species. Using a threshold of DBH $\geq$ 50 cm, 155 individuals across all the recorded trees were determined as large trees in the community, one-third of which were protected plants in China. By setting the top 5% in DBH of a certain tree species as the standard, this study defined large individual criteria for six local typical tree species. Large trees and large individuals exhibited characteristics of contributing disproportionately to basal area despite low abundance. Population characteristics revealed different patterns, as follows: AN and PJ had large populations with smaller diameters, TA and PK had small populations with larger diameters, and BC and LO showed intermediate population sizes and diameters. For protected plant species, entire populations warrant priority conservation. For community-level large trees and species-specific large individuals, survival status requires heightened monitoring. Further studies should broaden and deepen the understanding of large trees through larger sample sizes, long-term monitoring data, and the incorporation of additional influencing factors.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d17070491/s1, Figure S1: Distribution of plots in this study; Table S1: Location of plots in this study.

Author Contributions: Conceptualization, D.K.; methodology, D.K.; formal analysis, Y.Y., Z.J. and D.K.; investigation, S.G. and Y.L.; writing—original draft preparation, Y.Y.; writing—review and editing, D.K.; supervision, J.L.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Training Program of Innovation and Entrepreneurship for Undergraduates of Beijing Forestry University.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

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

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