

# Structural diversity and conservation implications of *Parrotia subaequalis* (Hamamelidaceae), a rare and endangered tree species in China

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## Abstract

*Parrotia subaequalis* (H. T. Chang) R.M. Hao & H.T. Wei is a rare and endangered Tertiary relict tree that is endemic to subtropical China. However, little is known about its growth condition and relationship with associated tree species. Here, for the first time we measured the structural diversity of *P. subaequalis* communities at three representative sites in eastern China using four structural indices, including mingling, tree-tree distance, and diameter and tree height differences. The results showed that: 1) Collectively, most *P. subaequalis* and associated tree species were small and mid-sized classes in tree height, and small-sized class in diameter; 2) There were two or more other tree species around most of *P. subaequalis* individuals across the three sites; 3) Overall, the mean distance between reference trees and their neighbors was mainly 1–2 m. Our results indicated that a strong interspecific competition existed between *P. subaequalis* and its associated tree species. Meanwhile, although the reference tree *P. subaequalis* had slight advantages in both horizontal and vertical planes, we think that it is necessary to take some effective measures to reduce the interspecific competition and thereby keep it at a proper successive stage. In addition, we also discuss the protection level of *P. subaequalis* in China, and propose to keep this species at the First-Grade State Protection.

## Keywords

Competition, neighboring tree, *Parrotia subaequalis*, population, structural indices

## Introduction

Analyzing species composition, structure and function of endangered plant communities is essential for understanding the growth of a target (endangered) species, its relationship with surrounding tree species and predicting its population dynamics (Hui et al. 2019; Alavi et al. 2020). Generally, on a small scale, the horizontal and vertical structure of a forest community is largely influenced by the arrangement, position, and mixture degree of the surrounding tree species and their competition for light, water, minerals, space and other environmental resources (Pommerening 2002; Ruprecht et al. 2010). For those endangered species which have a limited distribution within a certain area, their populations usually share similar climate, soil, human disturbance and other environmental factors. For this reason, it seems reasonable to study the growth status of an endangered species and its relationship with surrounding tree species by analyzing structural diversity indices.

The structural group of four refers to a structure unit consisting of a reference tree, or a reference point, and the three nearest neighbors in the vicinity of the tree or point, which is designed to reveal spatial patterns of a particular tree cohort (Gadow and Hui 2002; Gadow et al. 2012). Because of time-saving, low cost, and practicality, this approach has been widely used in forest surveys (Hui and Gadow 2003; Wang et al. 2016). More importantly, the structural diversity indices provided by this method can accurately reflect the growth status of the reference tree and the differences between the reference tree and its neighbors, thus revealing the spatial structure of the population (Ni et al. 2014). More recently, it has been gradually applied to characterize forest spatial structure and diversity, and thereby provide reference idea for ecological protection of rare and endangered plant species (Ruprecht et al. 2010; Jimu et al. 2012; Sefidi et al. 2015). For example, Zhang et al. (2018a) used this approach to measure the structural diversity of Chinese yew (*Taxus wallichiana* var. *mairii*) population in an *ex situ* conservation established in Nanjing of eastern China, and considered that these yews faced strong interspecific competition from their neighbors and that most yews were found beneath a single tall neighboring tree. Accordingly, this result provides a theoretical basis for the protection of Chinese yew. Sefidi et al. (2015) studied the structural diversity of Persian ironwood (*Parrotia persica*) in northern Iran, and found that Persian ironwood almost grew in fairly pure forests in three sampled plots and the interspecific competition was weak.

*Parrotia subaequalis* (H. T. Chang) R. M. Hao et H. T. Wei, endemic to eastern China, is a sibling species of *P. persica* belonging to the family Hamamelidaceae. *P. subaequalis* is of great value in a variety of aspects. First, this species is a relict living-fossil plant originating from the Tertiary, which may play a significant role in reflecting the phylogeny of Hamamelidaceae (Hao et al. 1996; Zhang et al. 2019) and the origin of early angiosperms (Li and Tredici 2008; Zhang et al. 2021). Second, *P. subaequalis* yields good timber with fine wood-grain, being hard and heavy (Zhong 2016). Third, this species has a straight trunk, exfoliating bark and its leaves turning red in autumn, which makes it a bonsai or an ornamental tree (Li and Zhang 2015; Zhang 2020). Due to illegal deforestation, the population of *P. subaequalis* has declined dramatically and its distribution area has decreased sharply over the past several decades (Ma and Zhang 2009). Therefore, it has been

on the 'List of the Important Wild Plants for Conservation in China (first passel)' since 1999 (Yu 1999). In recent years, there have been sporadic findings regarding wild individuals of *P. subaequalis* that have occurred in mountainous areas of Zhejiang, Jiangsu, Anhui and Henan provinces (Zhu 2016; Wang and Fan 2017; Li et al. 2018; Wang et al. 2018). Nonetheless, its current wild populations are mainly distributed in some isolated mountainous areas of Anhui, Jiangsu and Zhejiang Province, eastern China.

Up to now, most of the previous studies were focused on genetic diversity (Zhang et al. 2019; Zhang et al. 2021), physiological ecology (Yue et al. 2006; Yan et al. 2008) and distribution pattern (Gong et al. 2012; Zhang et al. 2018b) of *P. subaequalis*, but little attention has been paid to the growth conditions and its relationship with neighboring trees. Zhang et al. (2016) analyzed the intraspecific and interspecific competition intensities of *P. subaequalis* with Hegyi single-tree competition index model, in Wanfo Nature Reserve of Anhui Province, and found that the main competitive intensity of *P. subaequalis* population came from interspecific competition. In fact, this method only considers the distance between the target species *P. subaequalis* and its neighboring trees, but fails to take into account the mixture degree of surrounding species and the influence of neighbors in the horizontal and vertical planes. More importantly, because *P. subaequalis* is mainly distributed in the three provinces of Jiangsu, Anhui and Zhejiang (Wu and Raven 2003), the growth status of *P. subaequalis* at different locations and its relationship with neighboring trees still remain unclear.

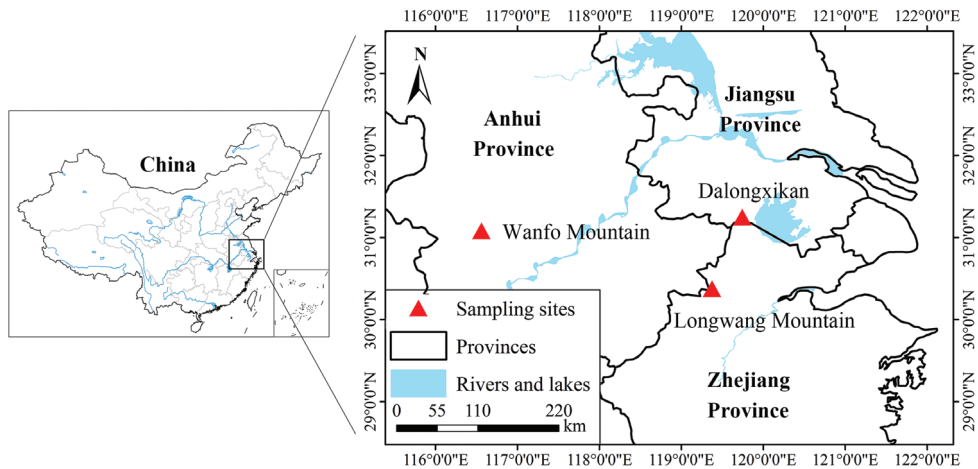
In this study we selected three representative distribution sites of *P. subaequalis*, analyzed the structural indices of target species and neighboring trees by using the structural group of four to reveal the growth of *P. subaequalis* within its main distribution areas. Our specific objectives are as follows: 1) to analyze the species composition of *P. subaequalis* community in the three sites, and the mixture and competition between *P. subaequalis* and neighboring trees; 2) to compare the differences between *P. subaequalis* and neighboring trees both in the horizontal and vertical planes across the three sites; 3) based on its characteristics of structural diversity in different sites, to provide some suggestions for the protection of *P. subaequalis* populations.

## Methods

### Study area

The study was carried out at three subtropical forests selected from different geographical locations in eastern China (Fig. 1). Each site has a considerable number of wild *P. subaequalis* adults, most of which occur in sunny slope.

The first study site (31°03'N, 116°28'E) is Wanfo Mountain (WF), located in the south-west of Shucheng County, Anhui Province, where the average elevation is over 500 m and the highest attitude is 1539 m. This area belongs to the subtropical humid monsoon climate zone, with characteristics of four distinct seasons, a mild climate and adequate rainfall. The mean annual temperature of WF is 13.6 °C and the annual precipi-



**Figure 1.** Distribution of sampling sites of *Parrotia subaequalis* populations in eastern China.

tation is 1300 mm, while the extreme maximum temperature is 39.0 °C and the extreme minimum is – 10.3 °C. Here, yellow soil and brown soil are the main soil types (Zhang et al. 2016). The main vegetation types are composed of evergreen and deciduous broad-leaved mixed forest, deciduous broad-leaved forest and coniferous forest, but *P. subaequalis* population occurs in deciduous broad-leaved forests with only a few evergreen trees, with other dominant species such as *Cyclobalanopsis glauca*, *Pistacia chinensis*, *Celtis sinensis*.

The second study site (31°14'N, 119°49'E) is Dalongxikan (DL), located in Longchishan-Xiaoheigou Nature Reserve in Yixing City, Jiangsu Province. Here the highest altitude is 500 m. This area also has the subtropical humid monsoon climate, with a mean temperature of 15.7 °C and an annual precipitation of 1200 mm, while the extreme maximum temperature is 44.0 °C and the extreme minimum is – 10.0 °C. The main zonal soil is yellow soil (Li and Zhang 2015). The main vegetation type is the subtropical evergreen and deciduous broad-leaved mixed forest, with the dominant species including *Dalbergia hupeana*, *Pistacia chinensis* and *Cyclobalanopsis glauca*.

The third study site (30°23'N, 119°23'E) is Longwang Mountain (LW), located in Longwangshan National Nature Reserve in Anji County, Zhejiang Province. Here the highest altitude is 1587.4 m. The region has the subtropical humid monsoon climate and the mean annual temperature is 15.5 °C, with an extreme maximum of 40.3 °C and an extreme minimum of – 12.2 °C. It has a mean annual precipitation of 1213.4 mm. The main soil types here are yellow soil, red soil, and yellow brown soil (Ren et al. 2012). Deciduous broad-leaved forest is the dominant vegetation type here.

Based on our field survey, we established a 1600 m<sup>2</sup> (40 m × 40 m) plot for WF, a 900 m<sup>2</sup> (30 m × 30 m) plot for DL and a 1600 m<sup>2</sup> (40 m × 40 m) plot for LW respectively in July, 2020. In WF and LW we established a grid of 64 sampling points respectively while in DL with a small distribution area of *P. subaequalis*, we thereby established a grid of 36 sampling points.

Following the sampling approach of Ruprecht et al. (2010), a single *P. subaequalis* which was the closest to the sampling point may be identified as a reference tree at each plot

(WF:  $n = 54$ , DL:  $n = 33$ , LW:  $n = 54$ ). Meanwhile, we identified the three trees nearest the reference tree as neighboring trees. And this structural group of four (a reference tree and their three nearest neighbors) was considered as a unit for measuring the structural indices. Accounting for a number of small-sized *P. subaequalis* in these plots, the reference trees and their neighboring trees selected as part of this unit had to be at least 4.0 cm of DBH. If one of the selected neighboring trees was located outside the perimeter of the sampling plot, the second nearest neighbor was measured so that all the four trees of this unit were within the plot (Sefidi et al. 2015; Zhang et al. 2018a). At each plot, we recorded the tree species, the number, diameter, height and the distance between a reference tree and its neighbors.

## Data analyses

In this study, we employed several widely used structural indices to characterize the distribution of stems and species of *P. subaequalis* forests across the three sites.

Mingling index ( $M_i$ ) (Pommerening 2002) describes the probability that neighboring trees around a reference tree belong to the same species. It shows the distribution of tree species and spatial arrangement around the reference tree. This index is calculated as:

$$M_i = \frac{1}{n} \sum_{j=1}^n v_{ij} \quad (1)$$

when the reference tree ( $i$ ) and its one neighbor ( $j$ ) are of the same species, the value of  $v_{ij}$  is 0. If they are different, the value is 1. And here  $n$  is the total number of neighboring trees, where  $n$  is 3 in this equation. So  $M_i$  has four values (0.00, 0.33, 0.67, 1.00). The smaller the value of  $M_i$  is, the higher probability that neighbors are of the same species as the reference tree. In contrast, the bigger the  $M_i$  is, the higher the probability that the neighbors and the reference tree belong to different species.

Tree-tree interval index ( $D_i$ ) (Ruprecht et al. 2010) refers to the average distance between a reference tree and its neighbors. It can reflect the density of the forest stand. Its calculation is:

$$D_i = \frac{1}{n} \sum_{j=1}^n s_{ij} \quad (2)$$

Here,  $s_{ij}$  means the distance between a reference tree ( $i$ ) and its one neighbor ( $j$ ). In other words, the larger value of  $D_i$  is, then the trees are further apart, while the lower value means that trees are closer together.

The diameter differentiation index ( $TD_i$ ) (Ruprecht et al. 2010) represents the difference in horizontal plane between a reference tree and its neighbor. Its calculation is:

$$TD_i = \frac{1}{n} \sum_{j=1}^n (1 - r_{ij}) \quad (3)$$

where  $r_{ij}$  is the ratio between the smaller diameter and the larger diameter.

The height differentiation index ( $HD$ ) (Ruprecht et al. 2010) describes the variation in the vertical plane within the forest stand. Its calculation is:

$$HD_i = \frac{1}{n} \sum_{j=1}^n (1 - r_{ij}) \quad (4)$$

where  $r_{ij}$  is the ratio of the smaller height and the larger height.

Distribution of  $TD_i$  ( $HD_i$ ) for *P. subaequalis* showed two value types: positive values (dominance of reference tree compared to its neighbors) and negative values (dominance of neighboring trees compared to reference tree). In order to quantify this difference, we divided the differentiation indices ( $TD_i / HD_i$ ) into four categories that followed the work by Pommerening (2002) and Zlatanov et al. (2013) in order to allow comparisons: i) Small differentiation ( $|TD_i / HD_i| = 0.0-0.3$ : the average size of a neighbor is 0–30% larger or smaller than *P. subaequalis*); ii) Average differentiation ( $|TD_i / HD_i| = 0.3-0.5$ : the average size of a neighbor is 30–50% larger or smaller than *P. subaequalis*); iii) Large differentiation ( $|TD_i / HD_i| = 0.5-0.7$ : the average size of a neighbor is 50–70% larger or smaller than *P. subaequalis*); iv) Tremendous differentiation ( $|TD_i / HD_i| = 0.7-1.0$ ; the average size of a neighbor is 70–100% larger or smaller than *P. subaequalis*).

We used MS-Excel 2019 to conduct basic data processing, and used Origin v8.0 software to draw frequency distribution of structural indexes (Origin Inc., Northampton, MA, USA).

## Data resources

The data underpinning the analysis reported in this paper are deposited in the Dryad Data Repository at <https://doi.org/10.5061/dryad.9kd51c5hm>.

## Results

### Associated species of *P. subaequalis* populations

There was a considerable difference in species composition for associated trees of *P. subaequalis* populations across the three sites. LW had 27 associated species, WF had 16 ones, and DL only had 14 ones. However, the first four top species at each site took obvious advantages in abundance, and these dominant species were very similar (Appendix 1). They were in order as follows: *P. subaequalis*, *Pistacia chinensis*, *Celtis sinensis*, *Cyclobalanopsis glauca* in WF, *Cyclobalanopsis glauca*, *P. subaequalis*, *Pistacia chinensis*, *Dalbergia hupeana* in DL, and *Celtis sinensis*, *P. subaequalis*, *Dalbergia hupeana*, *Platycarya strobilacea* in LW.

## Diameter and height distributions of *P. subaequalis* and other tree species

In WF there were 106 individuals of *P. subaequalis* (DBH  $\geq$  4 cm) (54 of which were reference trees) with a density of 6.6 / 100 m<sup>2</sup>. The tree height was classified into four categories, and most of *P. subaequalis* appeared in 2–4 m, with 46 trees. There were 110 individuals of other tree species at this site, with a density of 6.9 / 100 m<sup>2</sup>. The height class of other tree species had five categories, and most individuals also appeared in 2–4 m, with 38 trees (Fig. 2 WF). In DL there were 60 individuals of *P. subaequalis* (33 of which were reference trees) at a density of 6.7 / 100 m<sup>2</sup>. The tree height was classified into five categories, and most of *P. subaequalis* appeared in 8–10 m, with 23 trees. Meanwhile, there were 72 individuals of other tree species at this site, with a density of 8.0 / 100 m<sup>2</sup>. Their tree height also had five categories, and most of them appeared in 4–6 m (i.e. 22 trees) and 6–8 m (i.e. 23 ones) (Fig. 2 DL). In LW there were 83 individuals of *P. subaequalis* (54 of which were reference trees) with a density of 5.2 / 100 m<sup>2</sup>. Tree heights were classified into six categories, and most of *P. subaequalis* appeared in 6–8 m, with 48 trees. Meanwhile, there were 133 individuals of other tree species at this site, with a density of 8.3 / 100 m<sup>2</sup>. Their tree height had seven categories, and most of them appeared in 6–8 m (i.e., 73 trees) (Fig. 2 LW).

In total, for *P. subaequalis* and other tree species, both had the greatest number at 6–8 m (Fig. 2 Total). Furthermore, the great majority of all *P. subaequalis* within the sampled plots were less than 8 m in tree height; the same was true for other tree species herein.

In terms of diameter classes, there were four categories for *P. subaequalis* in WF, and most of *P. subaequalis* appeared in 4–8 cm, with 77 trees. There were five categories for other tree species in WF, and most of them also appeared in 4–8 cm, with 71 trees (Fig. 2). Likewise, most appeared at the same grade for both *P. subaequalis* and other tree species in DL and LW.

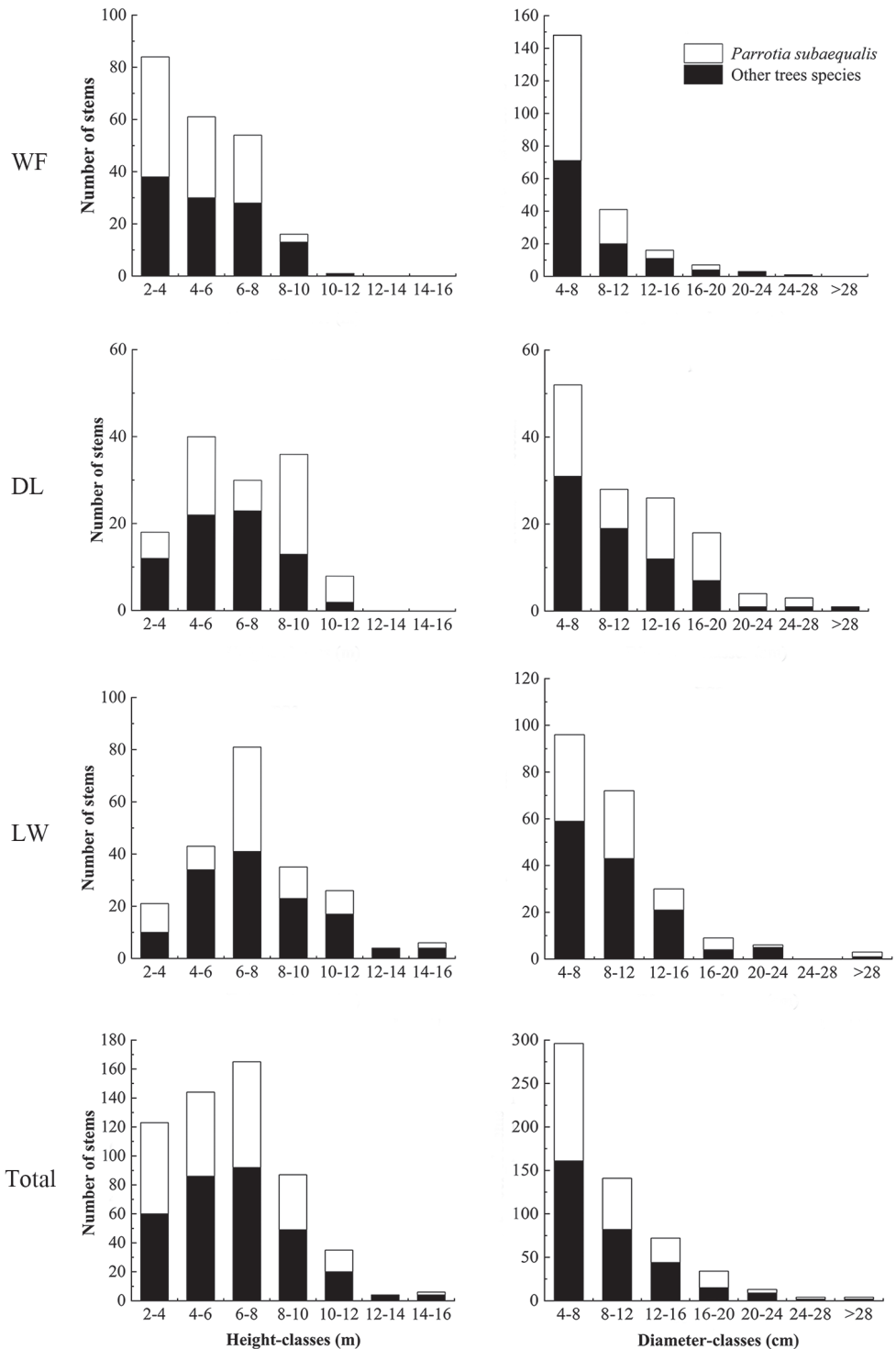
Collectively, most *P. subaequalis* and other tree species were small and mid-size classes in tree height, and small-size class in diameter.

## Structural diversity of the *P. subaequalis* populations

### Mingling index

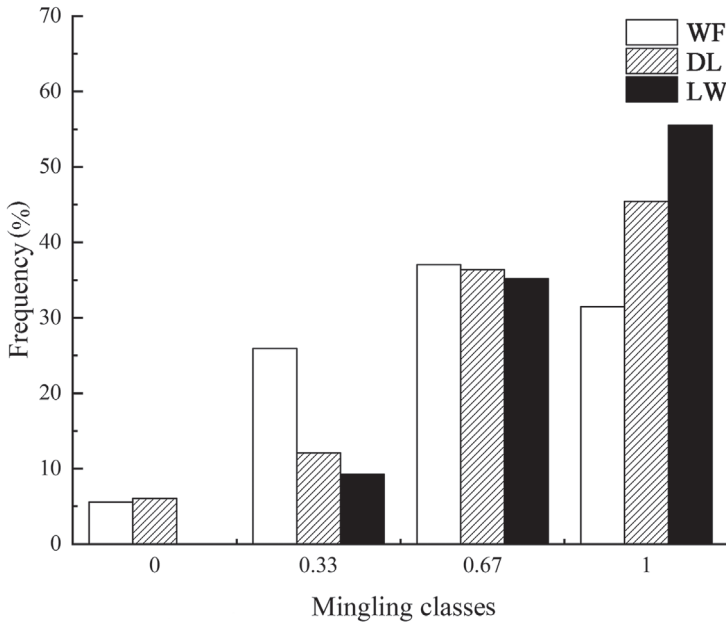
The mingling index ( $M_i$ ) describes composition and distribution within the stand. There are 4 potential values (0.00, 0.33, 0.67, 1.00) for each sample point to explain the configuration around the reference tree (Fig. 3). In WF, the relative frequency at  $M_i = 0.67$  was the highest (37.03%), followed by  $M_i = 1.00$  (31.48%). The situation in DL and LW were similar; the relative frequency was the highest at  $M_i = 1.00$ , followed by  $M_i = 0.67$ . Across the three sites, the relative frequency of  $M_i = 1.00$  and  $M_i = 0.67$  was the largest which means there were two or more other tree species around most of *P. subaequalis*. Viz. the neighboring trees of *P. subaequalis* were mainly other tree species.





**Figure 2.** Height and diameter class distributions for *P. subaequalis* and other tree species in eastern China.





**Figure 3.** Mingling classes for *P. subaequalis* stands in eastern China.

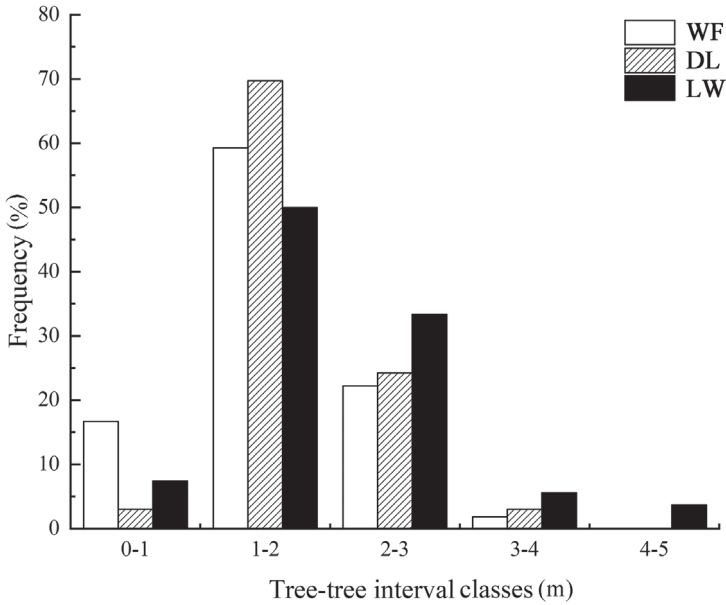
### Tree-tree interval index

The tree-tree interval index ( $D_i$ ) indicates the average distance between the reference trees and the three nearest neighboring trees. When this value is larger, the competition between them is weaker, otherwise the competition is stronger. We divided all of the sampling point measurements into five categories at a step interval of 1 m (Fig. 4). In WF, the average distance between the reference tree and neighbors was mostly 1–2 m, and its relative frequency was 59.26%. The same was true for the mean distance in both DL and LW, with a relative frequency of more than 50%. In addition, the mean distance between the reference trees and the three nearest neighboring trees was  $1.56 \pm 0.08$  m in WF,  $1.74 \pm 0.10$  m in DL,  $1.97 \pm 0.11$  m in LW respectively.

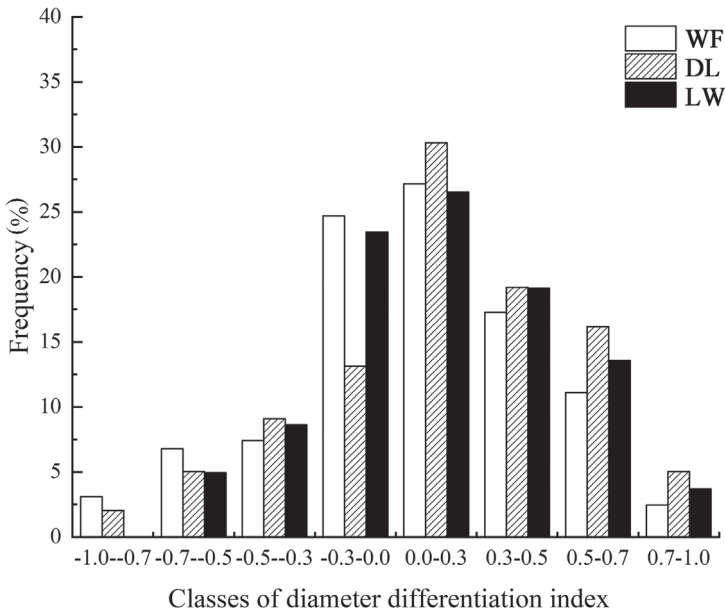
Overall, the mean distance between reference trees and their neighbors mainly appeared within 1–2 m, suggesting that a strong competition may exist between *P. subaequalis* and associated tree species.

### Diameter differentiation index

The diameter differentiation index ( $TD_i$ ) describes the horizontal difference between the reference tree and the three nearest neighboring trees. In WF and LW, the relative frequencies were the highest when the diameter difference class was 0.0–0.3, followed by the difference class was  $-0.3-0.0$  (Fig. 5). In DL, the relative frequencies at the difference class of 0.0–0.3 was the highest (30.3%), followed by the difference class of 0.3–0.5. Across the three sites, the probability of the positive differentiation values in



**Figure 4.** Tree-tree interval classes of *P. subaequalis* in eastern China.



**Figure 5.** Diameter differentiation classes of *P. subaequalis* in eastern China.

DBH between reference tree and its neighbors was greater than the probability of the negative differentiation values. Collectively, the average diameter of *P. subaequalis* was larger than those of the neighboring trees in the three plots. And *P. subaequalis* also had a slight advantage in the horizontal plane.

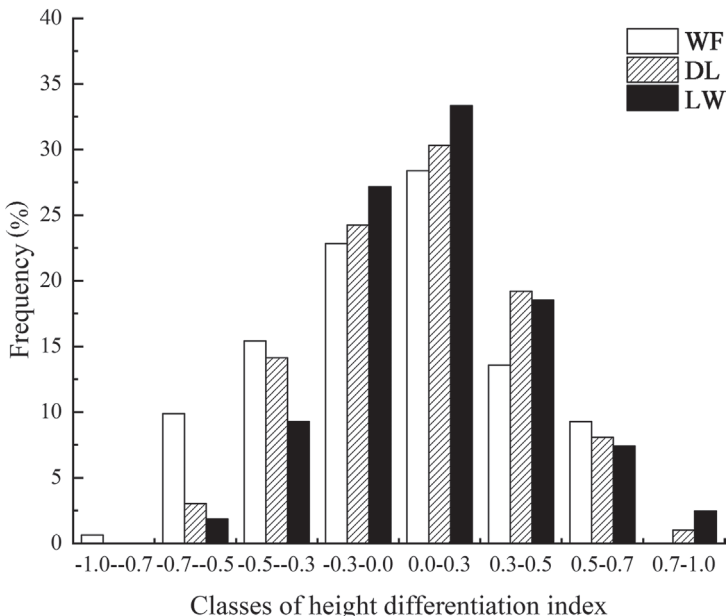
## Height differentiation index

The height differentiation index ( $HD_i$ ) shows the vertical difference between the reference tree and the three nearest neighboring trees. The height distribution had a similar pattern for these three plots as shown in Fig. 6. We found that the probability of the positive differentiation values in height was slightly greater than the probability of the negative values in the plots. Simultaneously, the relative frequency at the difference class of 0.0–0.3 was the highest, followed by the difference class of –0.3–0.0. Collectively, the average height of *P. subaequalis* was larger than those of its neighbors. And *P. subaequalis* had a slight advantage in the vertical plane.

## Discussion

### Competition and structural diversity within *P. subaequalis* communities

This study describes the characteristics of structural diversity of the endangered Tertiary relict Chinese tree *P. subaequalis* communities for the first time. Our results showed that the neighboring trees of *P. subaequalis* were largely non-*Parrotia subaequalis* across the three chosen representative sites in light of the main value with  $M_i$  (mingling index) = 0.67 and  $M_i = 1.00$  (Fig. 3). Meanwhile, the average distances between *P. subaequalis* and the three nearest-neighboring trees were mostly found within 1–3 m, with the majority at the average distance of 1–2 m (Fig. 4). This indicated that there was a strong interspecific competition between *P. subaequalis* and its associated tree



**Figure 6.** Height differentiation classes of *P. subaequalis* in eastern China.

species. This result is different from that of the Persian Ironwood *P. persica*, a rare and endangered plant endemic to northern Iran (Sefidi et al. 2015). Persian Ironwood has an average distance between trees of 6.0 m, with main value of  $M_i = 0.33$ , suggesting little interspecific competition within its stand plots, which mainly resulted from the serious human disturbance to Persian Ironwood populations (Ramezani et al. 2016). In contrast, the three sites of *P. subaequalis* in eastern China are all located in the provincial or national nature reserves, with relatively little current human disturbance. Moreover, all of the three sites are situated in the eastern subtropical region of China, with good combination of water and temperature (Song 2013), which is suitable for the growth of a variety of tree species including *P. subaequalis*.

In addition, the current result is consistent with a previous study by Zhang et al. (2016) conducted in Wanfo Mountain, Anhui Province. However, our study demonstrates that although there were some differences in species composition of the *P. subaequalis* communities, their structural diversity indexes are very similar across the three sites representing its distribution area in China. The result from this study is also consistent with findings from sample-plot survey of endangered *Carpinus tientaiensis*, whose growth and propagation mainly resulted from interspecific competition (Yao et al. 2021).

Our results also showed that the reference tree *P. subaequalis* had slight advantages in both horizontal and vertical planes (Fig. 5 and Fig. 6). However, we speculated that in the process of late succession this species may face intense interspecific and intraspecific competition which would gradually cause it to lose such advantage. The reasons are as follows: (1) The target tree species (i.e., *P. subaequalis*) is similar in ecological characteristics to its main associated species, such as *Celtis sinensis*, *Pistacia chinensis*, *Cyclobalanopsis glauca*, *Dalbergia hupeana* and *Platycarya strobilacea* (Appendix 1). All of them are light-demanding tree species, which can resist drought, endure barren conditions, and propagate by root sprouts (Chen and Sun 2015; Wu et al. 2015; Rao et al. 2020). Nevertheless, *P. subaequalis* has a shallow root system while the other associated trees have deep root systems (Chen and Sun 2015). Compared with the associated tree species, *P. subaequalis* has a higher light compensation point and a lower light saturation point, which indicates that it has a narrower light adaptation range (Zhu et al. 2008). Accordingly, these result in a weak photosynthetic capacity and material accumulation capacity for *P. subaequalis*. Considering its relatively slow growth rate, the reference tree *P. subaequalis* may gradually suffer disadvantage due to interspecific competition. (2) The communities in the three sampling sites were all deciduous broad-leaved forests. According to the forest succession in the subtropical region of eastern China, the succession sequence of deciduous broad-leaved forest is generally as follows (Zhang et al. 1999; Song 2013): (a) coniferous forest, (b) coniferous and broad-leaved mixed forest, (c) deciduous broad-leaved forest dominated by light-demanding tree species, (d) deciduous broad-leaved forest dominated by shade-tolerant tree species, (e) climax community (containing a few evergreen species). According to our investigation, the dominant tree species across the three sites were light-demanding species. *P. subaequalis* communities is currently at the stage of deciduous broad-leaved forest dominated by light-demanding tree species, that is, it was in the early stage of forest community succession in subtropical forest. Therefore, with succession proceeding, the dominant tree species in the communities will be gradually changed into mesophytic species

(i.e., semi-shade-tolerant species). Actually, the seedlings and saplings of *P. subaequalis* are able to survive and endure in low light conditions, which will become a limiting factor for advanced *P. subaequalis* in the later stage (Yan et al. 2008; Geng et al. 2015). Consequently, the population of *P. subaequalis* will show a declining trend with succession proceeding.

### Conservation implications for *P. subaequalis* populations

Based on our findings, we propose to take some measures to reduce the interspecific competition for *P. subaequalis* stands. More specifically, such treatments may include thinning, or cutting off some big branches of the associated tree species growing around *P. subaequalis* individuals. In doing so, *P. subaequalis* population can obtain adequate light and living space, and thereby be maintained at a proper successive stage.

In addition, in the 2020 draft of List of the Important Wild Plants for Conservation in China, which is open to public advices and suggestions, *P. subaequalis* was relegated from national protection level I to level II in China (Qin Haining, personal communication). We think that such treatment is questionable. In the last several decades, a few wild populations of *P. subaequalis* from different locations were recorded in China (Li et al. 2018; Wang and Zhang 2019), but each had a small population size, especially for mature individuals. Recent studies indicate that this species has a relatively high genetic diversity and genetic differentiation (Zhang et al. 2019). Nevertheless, due to a low germination rate (Deng et al. 1997), slow growth (Li and Zhang 2015), weak competitiveness, serious insect herbivory (Adroit et al. 2020), in tandem with habitat destruction and fragmentation (Ma and Zhang 2009), the distribution range and population size of *P. subaequalis* have changed little or even continued to decline in some regions. To sum up, we propose to keep this species at the First-Grade State Protection so as to conserve its wild populations as much as possible nationwide.

In brief, our findings highlight that in addition to concern about its growth performance, the interaction relationship between the target species and its associated tree species, especially interspecific competition, and progressive succession dynamic of the current community should be involved in active protection practice for conservation of a rare and endangered tree species in the long run.

### Conclusions

This study is the first to measure the structural diversity of *P. subaequalis* communities at three representative sites in eastern China. Our results indicated that a strong interspecific competition existed between *P. subaequalis* and its associated tree species. Meanwhile, although the reference tree *P. subaequalis* had slight advantages in both horizontal and vertical planes, we think that it is necessary to take some effective measures to reduce the interspecific competition. In doing so, we can maintain its population stability, and thereby keep it at a proper successive stage. In addition, we also discussed the protection level of *P. subaequalis*, and propose to keep this species at the First-Grade State Protection rather than degrade its status into the second grade nationwide.

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## Appendix I

Table AI. The main associated trees of *Parrotia subaequalis* in eastern China.

Appendix 1 The main associated trees of <i>Parrotia subaequalis</i> in eastern China					
Site	Species	Genus	Family	Individuals	
WF	<i>Parrotia subaequalis</i>	<i>Parrotia</i>	Hamamelidaceae	52	
	<i>Pistacia chinensis</i>	<i>Pistacia</i>	Anacardiaceae	25	
	<i>Celtis sinensis</i>	<i>Celtis</i>	Cannabaceae	22	
	<i>Cyclobalanopsis glauca</i>	<i>Cyclobalanopsis</i>	Fagaceae	21	
	<i>Cladrastis wilsonii</i>	<i>Cladrastis</i>	Fabaceae	11	
	<i>Zelkova schneideriana</i>	<i>Zelkova</i>	Ulmaceae	6	
	<i>Pteroceltis tatarinowii</i>	<i>Pteroceltis</i>	Cannabaceae	5	
	<i>Dalbergia hupeana</i>	<i>Dalbergia</i>	Fabaceae	5	
	<i>Fraxinus insularis</i>	<i>Fraxinus</i>	Oleaceae	4	
WF	<i>Symplocos paniculata</i>	<i>Symplocos</i>	Symplocaceae	3	
	<i>Quercus variabilis</i>	<i>Quercus</i>	Fagaceae	2	
	<i>Ulmus pumila</i>	<i>Ulmus</i>	Ulmaceae	2	
	<i>Lindera glauca</i>	<i>Lindera</i>	Lauraceae	1	
	<i>Litsea rotundifolia</i> var. <i>oblongifolia</i>	<i>Litsea</i>	Lauraceae	1	
	<i>Photinia serratifolia</i>	<i>Photinia</i>	Rosaceae	1	
	<i>Camellia cuspidata</i>	<i>Camellia</i>	Theaceae	1	
	DL	<i>Cyclobalanopsis glauca</i>	<i>Cyclobalanopsis</i>	Fagaceae	29
		<i>Parrotia subaequalis</i>	<i>Parrotia</i>	Hamamelidaceae	27
<i>Pistacia chinensis</i>		<i>Pistacia</i>	Anacardiaceae	10	
<i>Dalbergia hupeana</i>		<i>Dalbergia</i>	Fabaceae	10	
<i>Phyllostachys edulis</i>		<i>Phyllostachys</i>	Poaceae	5	
<i>Tilia miqueliana</i>		<i>Tilia</i>	Malvaceae	4	
<i>Celtis sinensis</i>		<i>Celtis</i>	Cannabaceae	3	
<i>Quercus serrata</i>		<i>Quercus</i>	Fagaceae	3	
<i>Fortunearia sinensis</i>		<i>Fortunearia</i>	Hamamelidaceae	3	
<i>Ilex chinensis</i>		<i>Ilex</i>	Aquifoliaceae	1	
<i>Maclura tricuspidata</i>		<i>Maclura</i>	Moraceae	1	
<i>Fraxinus insularis</i>		<i>Fraxinus</i>	Oleaceae	1	
<i>Meliosma oldhamii</i>		<i>Meliosma</i>	Sabiaceae	1	
<i>Acer tataricum</i> subsp. <i>ginnala</i>		<i>Acer</i>	Sapindaceae	1	
LW		<i>Celtis sinensis</i>	<i>Celtis</i>	Cannabaceae	30
	<i>Parrotia subaequalis</i>	<i>Parrotia</i>	Hamamelidaceae	29	
	<i>Dalbergia hupeana</i>	<i>Dalbergia</i>	Fabaceae	14	
	<i>Platycarya strobilacea</i>	<i>Platycarya</i>	Juglandaceae	13	
	<i>Zelkova schneideriana</i>	<i>Zelkova</i>	Ulmaceae	12	
	<i>Morus cathayana</i>	<i>Morus</i>	Moraceae	8	
	<i>Fortunearia sinensis</i>	<i>Fortunearia</i>	Hamamelidaceae	7	
	<i>Diospyros lotus</i>	<i>Diospyros</i>	Ebenaceae	6	
	<i>Fraxinus insularis</i>	<i>Fraxinus</i>	Oleaceae	5	
	<i>Cornus kousa</i> subsp. <i>chinensis</i>	<i>Cornus</i>	Cornaceae	4	
	<i>Lindera glauca</i>	<i>Lindera</i>	Lauraceae	4	
	<i>Euonymus carnosus</i>	<i>Euonymus</i>	Celastraceae	3	
	<i>Albizia kalkora</i>	<i>Albizia</i>	Fabaceae	3	
	<i>Quercus fabri</i>	<i>Quercus</i>	Fagaceae	3	
	<i>Poliothyrsis sinensis</i>	<i>Poliothyrsis</i>	Salicaceae	3	
	<i>Acer elegantulum</i>	<i>Acer</i>	Sapindaceae	3	
	<i>Acer henryi</i>	<i>Acer</i>	Sapindaceae	3	
	<i>Cyclobalanopsis gracilis</i>	<i>Cyclobalanopsis</i>	Fagaceae	2	
	<i>Symplocos sumuntia</i>	<i>Symplocos</i>	Symplocaceae	2	
	<i>Alangium chinense</i>	<i>Alangium</i>	Cornaceae	1	
	<i>Rhododendron ovatum</i>	<i>Rhododendron</i>	Ericaceae	1	
<i>Cyclobalanopsis glauca</i>	<i>Cyclobalanopsis</i>	Fagaceae	1		
<i>Cyclobalanopsis myrsinifolia</i>	<i>Cyclobalanopsis</i>	Fagaceae	1		
<i>Deutzia scabra</i>	<i>Deutzia</i>	Hydrangeaceae	1		
<i>Broussonetia papyrifera</i>	<i>Broussonetia</i>	Moraceae	1		
<i>Maclura tricuspidata</i>	<i>Maclura</i>	Moraceae	1		
<i>Styrax dasycanthus</i>	<i>Styrax</i>	Styracaceae	1		

WF: Wanfo Mountain, Shucheng County, Anhui Province; DL: Dalongkikan, Yixing City, Jiangsu Province; LW: Longwang Mountain, Anji County, Zhejiang Province.