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CASE REPORT

Comparison of community structures of *Phoebe chekiangensis* pure forests and heterogeneous mixed forests

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ABSTRACT

Taking the 13 years pure artificial forest *Phoebe chekiangensis* and heterogeneous mixed forests in Tiantong mountain, Zhejiang Province as the research object, the characteristics of stand development, tree competition differentiation, tree height/breast diameter ratio and dominant wood growth were compared and analyzed from the perspective of ecology. The results show that compared with pure forests, the growth advantages of heterogeneous mixed-age forests were significant. Average breast diameter growth of stand increased 1.8%; the growth of single plant wood accumulation increased 7.4%. The relationship between tree height and diameter showed that the high growth of *Phoebe chekiangensis* individuals in the heterogeneous mixed forest was significantly promoted, and the high growth of the tree was 8.4% higher than that of pure forest. 1–5 grade wood scale sizes *Phoebe chekiangensis* in heterogeneous mixed forests and pure forests are ranked grade 3 (43.7%) > grade 2 (26.5%) > grade 4 (15.7%) > grade 1 (12.9%) > grade 5 (1.2%); grade 3 (34.7%) > level 2 (25.6%) > level 4 (20.0%) > level 1 (18.2%) > level 5 (1.2%); the straight-diameter structure shows a normal distribution, and the degree of differentiation of pure forests is greater than that of heterogeneous forests. The dominant trees of *Phoebe chekiangensis* pure forest and heterogeneous forest accounted for 18.2% and 12.9% of the total number of plants respectively, providing a reserve of 51.1% and 35.4% respectively, reflecting the contribution of dominant trees caused by the self-thinning effect.

Keywords: *Phoebe Chekiangensis*; Artificial Pure Forest; Heterogeneous Mixed Forests; Stand Structure

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1. Introduction

The structure is the basis of function, and the diameter structure, tree species composition structure and spatial structure of the stand determine the function of the stand. Although the structure of forest stands has been studied for nearly a hundred years, in different periods, it has changed with the purpose of forest management, and has gradually developed from the past benefits of timber production and economy to the goal of attaching equal importance to multiple benefits. In order to overcome the problems of single structure, inefficient function and low productivity of plantation forests, German forester Gayer put forward the management theory of "near-naturalization of planted forests", advocated the use of indigenous tree species, and advocated that the establishment, cultivation and logging methods of forest stands should be as close as possible to "potential natural vegetation", and its business objectives were: mixed forests—heterogeneous forests—multi-layer forests. The core of the cultivation process is the "single tree target tree" management system, which is an effective method for the management and cultivation of plantations. *Phoebe chekiangensis* is a precious tim-

ber tree species endemic to China, with a small natural distribution area limited to Zhejiang, Fujian, Jiangxi and southern Anhui. Due to its good material, medium growth rate, stress resistance, and strong germination ability[1-7], it was introduced to the Yinzhou Tiantong Forest Farm after 2002, becoming one of the most important afforestation tree species recovered after the cleaning of the damaged Masson pine forest. This paper compares and analyzes the productivity, diameter structure and growth characteristics of pure and mixed forests from the perspective of ecology, discusses the structural differences between the two, and provides a reference for the cultivation of plantations and sustainable forest management of precious timber species.

2. Overview of the test area

The test site is located in Tiantong Forest Farm (29°48'N, 121°47'E) in Yinzhou District, Ningbo City, which belongs to the Subtropical humid monsoon climate. The average annual temperature is 16.2 °C; the annual accumulated temperature ≥10 °C is 5166.2 °C, the temperature index of Kira is 135 °C; the frost-free period is 237.8 d; the average annual precipitation is 1,375 mm, the evaporation is 1,320.1 mm, the relative humidity is 82%, the annual sunshine time is 2,057.9 h, and the sunshine rate is 47%. The natural vegetation of the survey area is the subtropical evergreen broad-leaved forest, and the dominant tree species in the hillside standing type are *Schima superba*, *Castanopsis fargesii* and *Castanopsis carlesii*) *et al.*; the dominant species in the gully stand type are *Choerospondias axillaris*, *Liquidambar formosana*, and *Machilus leptophylla*, *Machilus thunbergii*, etc., the composition of tree species is complex and the degree of diversity is high.

3. Research methods

The 13-year-old *Phoebe chekiangensis* pure forest and the heterogeneous mixed forest (I Acid II Phoebe, i.e. the main forest layer is *Choerospondias axillaris* and *Liquidambar formosana*, and the renewal layer is *Phoebe chekiangensis*) was selected as the research object. *Phoebe chekiangensis* pure forest was originally a citrus reticulata forest, which was harvested in the winter of 2002 and reclaimed with a specification of length 0.5 m × width 0.5 m × depth 0.35 m, 2 years old grade I and II seedlings (playing small mud balls) were used in March 2003 for afforestation; the initial planting density is 3,500/hm^{-2}, the heterogeneous mixed forest was originally a mixed forest of *Pinus massoniana* and *Choerospondias axillaris*, and all the pine trees died due to the damage of pine wood nematode disease. After the sick wood is cleared, the near-mature mother trees of *Choerospondias axillaris* and *Liquidambar formosana* on the forest land are retained. In the spring of 2003, the land was prepared and afforested with the above methods, and the initial planting density was 3,150/hm^{-2}. The locations of the two test sites are similar, the standing conditions are all valleys, and the terrain is relatively consistent. The status of the site is shown in **Table 1**.

Table 1. Growth of stand in the sample plot

Project	Sample plot	
	P_1	P_2
Stand type	Pure forest	Mixed forest of different ages
Area/hm^2	0.433	0.2
Age/a	13	40/13*
Altitude/m	110	120
Slope position	Low	Low
Slope direction	SE	SW
Gradient	10–15	10–16
Mother rock	Igneous rock	Igneous rock
Soil type	Red earth	Red earth
Soil thickness	90–120	90–120

The plots is set as 0.433/hm^{-2} and 0.2 hm^{-2} in the pure stand heterogeneous forest respectively. Each tree was surveyed in December 2013 to investigate plant names, quantities, breast diameter, crown and its renewal and health condition, and to calculate individual tree volume and stand accumulation volume. The single plant volume is calculated with the formula of Zhejiang Forestry Survey and Design Institute: $V = G\ (H + 3)f$, where V is the accumulation of a single plant, G is the area of the DBH, H is the height of the tree, and f is calculated by the figured number of 0.38. Accumulation = average wood volume per plant × number of stand-reserved plants.

Stand grading method uses each wood gauge data, the formula $r = d/D$ is adopted for the calculation, where: d is the DBH of the forest (cm) and D is the average breast diameter of the forest stand

(cm). It is divided into 5 levels based on the size of the r value[5], grade 1 wood: $r \geq 1.336$; grade 2 wood: $1.026 \leq r < 1.336$; grade 3 wood: $0.712 \leq r < 1.026$; grade 4 wood: $0.383 \leq r < 0.712$, grade 5 wood: $r < 0.383$.

Table 2. The growth comparison between pure forest and mixed forest of different ages

Stand type	Tree species	Age/a	Average ABH/cm	Height /m	Density		Breast height sectional area		Volume	
					Quantity/(a tree/hm^2)	Proportion /%	Quantity /(m^2/hm^2)	Proportion /%	Quantity /(m^3/hm^2)	Proportion /%
Pure forest	*Phoebe chekiangensis*	13	5. 7 ± 2. 04	3.80	3,460	100.0	8.83	100.0	22.87	100.0
mixed forest of different ages	*Choerospondias axillaris*	45	26	13.50	125	3.8	6.64	33.6	41.61	44.4
	Liquidambar formosana	45	25	13.00	100	3.0	4.91	24.9	29.85	31.9
	Phoebe chekiangensis	13	5. 8 ± 1. 74	4.12	3,100	93.2	8.19	41.5	22.16	23.7
	Total				3,325	100.0	19.74	100.0	93.62	100.0

4. Results and analysis

4.1 Comparison of the growth of Different Stands in *Phoebe chekiangensis*

From **Table 1** and **Table 2**, it can be seen that the standing conditions of *Phoebe chekiangensis*'s heterogeneous mixed forest and pure forest plot are about the same, but the growth of *Phoebe chekiangensis* in heterogeneous forest is significant. The average annual growth rates of *Phoebe chekiangensis*'s DBH and tree height in the heterogeneous forest were 0.45 cm and 0.32 m respectively, which were higher than 1.8% and 8.4% in pure forests respectively, and the high growth pole of *Phoebe chekiangensis* in the heterogeneous forest is significantly higher than pure forest ($P > 0.01$). The breast height sectional area of *Phoebe chekiangensis* in the heterogeneous forest is 8.19 m^2/hm^{-2}, which is slightly smaller than pure forest, mainly due to density. Judging from the amount of stand stock, the heterogeneous forest is as high as 93.62 m^3/hm^{-2}, which is 3 times higher than that of pure forests, of which *Phoebe chekiangensis* is 22.16 m^3/hm^{-2}, and the growth effect of *Phoebe chekiangensis* in heterogeneous forests is remarkable.

4.2 Differences in the height/DBH ratio of *Phoebe chekiangensis* in different stands.

The correlation of growth relationships that are prevalent between individuals in the forest indicates that different organs in the individual or the same organ with different directions increase in a certain geometric way. Changes in environmental conditions can make this geometric growth change to accommodate the changed growing environment[8]. The frequency distribution of the tree height/breast diameter ratio of individuals in different stands is shown in **Figure 1**. In pure forests, the tree height/breast diameter ratio of *Phoebe chekiangensis* is distributed at 0.35–1.25, presenting a normal distribution, where the majority have the ratio of 0.5–0.95, accounting for 84.4%. The tree height/breast diameter ratio of *Phoebe chekiangensis* in the heterogeneous forest is also distributed at 0.35–1.25, where majority have the ratio of 0.5–1.1, accounting for 89.5%. The tree height/breast diameter ratio of *Phoebe chekiangensis* in heterogeneous forests that greater than 0.8 accounts for 31.1%, while pure forests account for only 20.7%, and the difference between them was significant through the analysis of variance ($P < 0.01$). It can be seen that the heterogeneous mixed forest has a significant promoting effect on *Phoebe chekiangensis* in the growth of the trunk in the vertical direction (tree height), which is conducive to the robust growth of young trees of nanmu, and the development of individual trees are well-balanced, which alleviates intraspecific differentiation.

4.3 Differences in the structure of the diameter class in *Phoebe chekiangensis* of different stands

The diameter structure can correctly reflect the competitive relationship between stand growth and forest trees. With the growth of forest trees, the for-

est stands gradually closed, and the competition within and between tree species became fierce, and the forest began to differentiate to form hierarchical trees. The competitive state of stand is related to its distribution of diameter class and number of plants[9]. The distribution of diameter class reflects

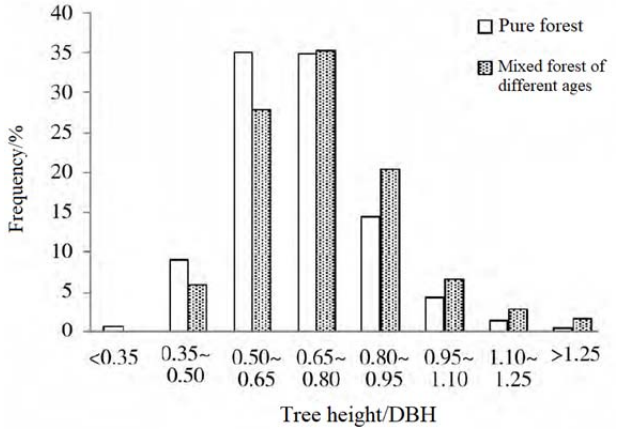

Figure 1. Frequency distribution of individual tree height/breast diameter ratio and chest diameter grade in different forest stands.

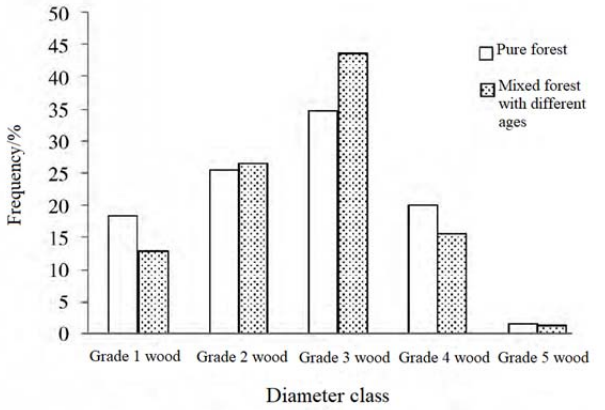

Figure 2. Frequency distribution of tree grading in different forest stands of *Phoebe chekiangensis*.

the existence and degree of differentiation. The wider the distribution range, the greater the possibility of the existence of the bipolar level, the higher the probability of differentiation; the distribution of trees of different diameter levels reflects the intensity of differentiation, and the greater the number of plants at the polar level, the greater the intensity of differentiation. As can be seen from **Figure 2**, the proportion of grade 1–5 wood in heterogeneous mixed forests, from largest to smallest, is grade 3 (43.7%) > grade 2 (26.5%) > grade 4 (15.7%) > grade 1 (12.9%) > grade 5 (1.2%), and the proportion of grade 1–5 wood in the pure forest from largest to smallest were grade 3 (34.7%) > grade 2 (25.6%) > grade 4 (20.0%) > grade 1 (18.2%) > grade 5 (1.2%). The distribution trend of the two vertical wood diameter grades is about the same, but the proportion is significantly different, and the proportions of grade 1 and grade 5 of heterogeneous mixed forests are significantly lower than those of pure forests; the proportion of grade 2–4 is about 85.9%, 5.6% higher than that of pure forest, indicating that the heterogeneous mixed forest is relatively balanced. At the same time, the proportion of grade 1 and grade 5 trees in heterogeneous mixed forests is 14.1%, which is 5.6% less than that of pure forests, indicating that the forest differentiation degree of pure forests is stronger, and the competition of trees is fierce, resulting in natural sparseness earlier than that of heterogeneous forests.

From **Figure 3**, it can be seen that the diameter structure distribution of *Phoebe chekiangensis* pure forest and heterogeneous forest is monomodal, and the diameter level distribution is continuous, indicating the lack of seedlings and young trees in the plantation.

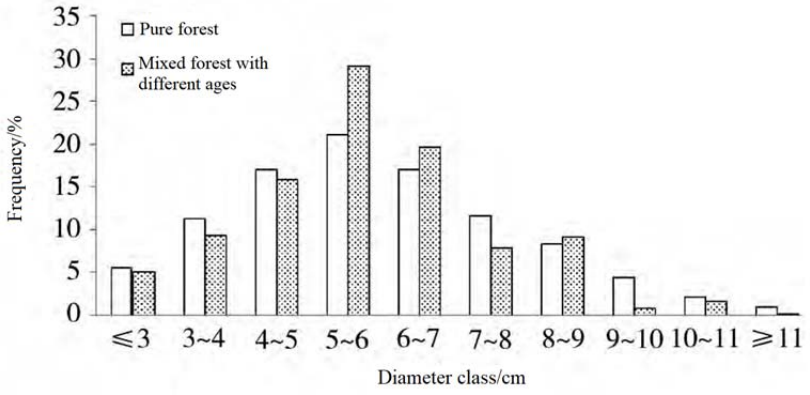

Figure 3. Diameter class distribution of the *Phoebe chekiangensis* of different stands.

4.4 The growth of dominant wood of *Phoebe chekiangensis* in different stands

Whether a large number of advantageous target wood can be cultivated and evenly distributed is a prerequisite for obtaining forest stand with high quality and high yield, and it is also a prerequisite for the cultivation of large-diameter timber. From **Table 3**, it can be seen that the numbers of dominant trees of *Phoebe chekiangensis* plantation pure forest and heterogeneous mixed forest are 630 and 401 respectively, accounting for 18.2% and 12.9% of the total number of plants, i.e. providing 51.1% and 35.4% of the forest stand accumulation, indicating that the main part that can provide harvest of forest management materials is completed by a small number of dominant trees. This provides valuable information for the cultivation of high-quality large-diameter materials in the future.

Table 3. Analysis of the effect of the number and diameter of dominant trees in *Phoebe chekiangensis* pure forest and mixed-age forest on the accumulation and growth of stand

Type	Total number of plants/(plant/hm^{-2})	Average diameter/cm	Average height/m	Growing stock/(m^3/hm^{-2})	Dominant trees that $D \geq 8$						
					Number of plants/(plant/hm^{-2})	Proportion/%	Average diameter/cm	Range/cm	Height/m	Volume/(m^3/hm^{-2})	Proportion/%
Pure forest	3,460	5.79	3.80	24.87	630	18.2	9.16	8–13	5.06 ± 0.51	12.72	51.1
Mixed forest of different ages	3,100	5.80	4.12	22.16	401	12.9	8.86	8–13	5.34 ± 0.81	7.84	35.4

5. Conclusions and discussions

Comparative analysis of stand growth and structure of artificial pure forests and heterogeneous mixed forests of *Phoebe chekiangensis* showed that compared with pure forests, the growth advantages of heterogeneous mixed forests were significant. The average thoracic diameter growth of the stand increased 1.8%, and the growth of single plant wood accumulation increased 7.4%. The analysis results of the relationship between tree height and breast diameter relationship analysis showed that the high growth of individuals in *Phoebe chekiangensis* was significantly promoted in the heterogeneous forest, and the high growth of trees was 8.4% higher than that of pure forests. The proportion of grade 1–5 wood in *Phoebe chekiangensis* of different ages ordered from the largest to the smallest are grade 3 (43.7%), > grade 2 (26.5%), > grade 4 (15.7%), > grade 1 (12.9%) > grade 5 (1.2%), and proportion of grade 1–5 wood in pure forest from the largest to the smallest are grade 3 (34.7%) > grade 2 (25.6%) > grade 4 (20.0%) > grade 1(18.2%) > grade 5 (1.2%); heterogeneous mixed forests have a small degree of differentiation and maintain high growth rates.

In this study, the height and breast diameter growth of *Phoebe chekiangensis* in the heterogeneous mixed forest was better than that in the pure forest, which was caused by the relatively low density of heterogeneous forests and the weak competition between tree species. Generally speaking, there is a density restriction effect among individuals in the forest stand, and the competition between individuals for space resources, material resources and light resources occurs due to the increase in density, resulting in limited resources that can only be allocated to those individuals with strong competitiveness. In this process, it is inevitable to eliminate some trees with weak competitiveness, and also put some trees in a unfavorable position, which will lead to a decline in the overall level of competitiveness, and ultimately make the growth of all individuals in the forest stand poor. On the contrary, at the same level of resource availability, if the number of competing individuals is small, the resource allocation is sufficient, which can ensure high growth of all individuals in the low-density stand. This phenomenon can be further demonstrated in the ratio of tree height and breast diameter of individuals in different stands in this study. The analysis of the tree high breast diameter ratio relationship showed that the tree height growth of *Phoebe chekiangensis* in the heterogeneous forest was significantly promoted, and the tree height growth was 8.4% higher than that of pure forest, which fully showed that the heterogeneous mixed forest was conducive to the growth of nanmu, the

development of individuals are well-balanced, and the intraspecific differentiation was moderated, providing a favorable growth environment for the stand. In the study, 18.2% and 12.9% of dominant (grade 1) woods were produced in the 13-year-old *Phoebe chekiangensis* forest, accounting for 51.1% and 35.4% of the accumulation respectively, indicating that the self-thinning effect of the forest stand developed according to a positive allometric growth relationship, that is, along with the process of self-thinning, the development process of the stand will inevitably be accompanied by the elimination of most individuals with weak competitiveness, and the total accumulation of forest stands must be contributed by a small number of competitive individual dominant trees. Therefore, in the current breeding process, the cultivation of the dominant target trees should be strengthened, which is of great significance for forest land productivity and forest renewal. Since *Phoebe chekiangensis* is a long-term cultivar, and the observation time of this study is limited, it is necessary to conduct long-term follow-up observation of its growth characteristics and the self-thinning effect of forest stands.

In view of the growth of two kinds of *Phoebe chekiangensis* forest stand in Tiantong Mountain, in order to promote the diameter and high growth of the dry timber stage as soon as possible, give play to the precious timber tree species as the main ecological benefits, and take into account other functional benefits, the traditional forestry cultivation mode should be changed and the near-natural management and cultivation should be adopted. In pure forests, due to the competitive differentiation of the stand, it can be tended once in the near future, removing the shrubs in the forest, and ing broad-leaved young trees such as Liquidambar formosana, Cinnamomum camphora and red Phoebe. Among the dominant (grade 1) trees, healthy, vigorous, dry and smooth young trees were selected as target trees, and numbered with sign, and the interfering trees within 4 m of them were thinned or transplanted to promote the rapid growth and even distribution of the target trees. For the mother trees that have borne fruits, it is necessary to strengthen the upper layer of light and the cleaning and care of woodland, promoting natural regeneration, and promoting the formation of single-layer forests as soon as possible. Biomass bamboo charcoal can be applied to plots with thin woodland and poor growth of Phoebe to improve the soil. In heterogeneous mixed forests, due to the low initial planting density and low degree of forest stand differentiation, it is also necessary to carry out the tending of removing the indocalamus and shrub vines once, and retain the top broadleaf saplings like *Choerospondias axillaris*, *Machilus leptophylla*, and *red Phoebe*, thereby increasing the hybridization and hierarchy of forest stands, improving the structure of forest stands, and realizing the transformation from plantation forest stand to zonal green broad-leaved forests.

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