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Species Diversity Characteristics of a Natural *Pinus taiwanensis* Community with Different Diameter Classes and Forest Densities

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Abstract: *Pinus taiwanensis* is a species endemic to China. This study selected four typical plots of *Pinus taiwanensis* in the natural secondary forest around Macheng City, in order to reveal the characteristics of and the relationships between different diameter classes (determined based on the diameter at breast height or DBH), forest densities and species diversity, as well as the similarities of species diversity of different plots within the community. The result showed that *Pinus taiwanensis* was the dominant species in the community. The ratio of *Pinus taiwanensis* trees of diameter class IV reached a peak of 19.46% of the total followed by diameter class VII at 18.92%. The study recorded 156 species of vascular plants from 130 genera of 71 families; *Pinus taiwanensis* was the dominant species in the community. When the forest density was 1200 trees ha^{-1} with the largest average diameter of DBH=36.779±4.444 cm, the diversity (Shannon index H'=1.6716) and the evenness (Pielou index E=0.6727) of the tree layer was the highest. When the forest density reached 1525 trees ha^{-1} with the lowest average diameter of DBH=18.957±5.141 cm, the richness (D_{ma}=5.4308), the diversity (H'=2.9612) and the evenness (E=0.8985) of all shrub layers climbed to the maximum. When the forest density was 1325 trees ha^{-1}, the richness (D_{ma}=5.8132), the diversity (H'=3.0697) and the evenness (E=0.9025) of all herb layers peaked. In terms of vertical structure, the average diversity indexes were herb layer>shrub layer>tree layer. High canopy density weakened light intensity in the community, causing a reduction in the species diversities of herbs and shrubs. The average similarity coefficient between the sample plots was 0.3356, which was at the medium dissimilarity level. External disturbances and improper management were major contributors to the low species diversity of the community. The implementation of scientific management measures is urgently needed to optimize the forest structures of *Pinus taiwanensis*, create a benign community environment, and promote species diversities and establish a stable forest community structure.

Key words: *Pinus taiwanensis*; diameter class; forest density; species diversity

1 Introduction

Pinus taiwanensis is a species endemic to China. *Pinus taiwanensis* has deep roots, and it grows well in middle or high mountain climates with high relative humidity, well-drained acid soils and sunny slopes. It can be adapted to barren soil, although this may contribute to growth retardation (Editorial Committee of *Flora Reipublicae Popularis Sinicae*, 1978). *Pinus taiwanensis* is the main constructive species in the middle mountainous areas of China's subtropical zone (Su et al., 2015); the species constitutes the evergreen coniferous forests of the subtropical zone. *Pinus taiwanensis* forests are one of the most representative forest types in China's subtropical middle mountainous areas with elevations of 800–1800 m.

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In the Dabieshan Mountains in eastern Hubei and southern Henan at elevations of 700–1600 m, the diameter class structure of most natural secondary forests of *Pinus taiwanensis* increased due to forest-enclosure for afforestation, and the forest gradually evolved into pure forest with *Pinus taiwanensi* being the dominant species. Over a long period of time, due to the improper management of natural forests, anthropogenic disturbances and complex natural environmental conditions, the natural secondary forests of *Pinus taiwanensis* have developed into forests featuring a simple community hierarchy, fewer tree species in tree layers, lower forest biodiversity and weak ecosystem stability. Therefore, it is difficult for *Pinus taiwanensis* to fulfill its appropriately ecological functions in the community (Li, 2008).

Tree size distribution and undergrowth vegetation diversity are basic attributes of forest structure, with both being closely related to forest biomass, carbon storage and total production (Niklas et al., 2003; Stephenson et al., 2011; Lai et al., 2013; Chao et al., 2015). Species diversity is one of the important characteristics of an organizational structure of a community, reflecting species richness and the stability and dynamics of a community (Hu et al., 2016). Tree size structure refers to the distribution of tree species in the forest based on the number of different tree-diameter groupings. Tree size structure gradually increases with the succession of the forest community. As the forest canopy density increases, the transmittance of the canopy decreases, and the growth and development of undergrowth vegetation are inhibited (Liu et al., 2016), thus causing changes to species diversity. At present, there are few studies of the correlations between the species diversity of undergrowth vegetation, and the size and density of the natural secondary forests of *Pinus taiwanensis*. Therefore, a discussion is needed of the correlation between tree size structures and species diversities of *Pinus taiwanensis* communities, and the correlation between varying community diversities and interference factors.

We chose natural secondary forests of *Pinus taiwanensis* with different forest ages in Sanhekou Township, Macheng City, Hubei Province as our research object. This study of forest densities, diameter classes, undergrowth species diversity, similarities of species diversity of different plots within the community, and causal factors aimed to reveal the correlations between the tree size structure and species diversity in natural *Pinus taiwanensis* forests of different ages. After developing a full understanding of the structural characteristics at different growing stages of *Pinus taiwanensis* forests, we recommended implementation of scientific, feasible forest-tending measures to promote the healthy succession of *Pinus taiwanensis* communities and maintain biodiversity and ecosystem stability (Jiang et al., 2015).

2 Research area and methods

2.1 The general situation of research area

We selected four 400 m^2 (20 m × 20 m) forest sites (plots) at Aimenguan Village in the Shizifeng forest farm (31°22'34"–31°23'32"N, 115°17'23"–115°21'41"E), Sanhekou Township, Macheng, China. Aimenguan Village is close to Shangcheng County in Henan Province and Jinzhai County in Anhui Province. The area has a subtropical continental humid monsoon climate and is part of the Jianghuai microclimate zone. It is characterized by abundant rainfall with rainy weather in the hot season, with more hours of sunshine and higher accumulated temperatures. Annual solar radiation is 96.9–112.5 kcal m^{-2}, and this is the highest level in the whole of Hubei Province (Dong, 2016). Annual sunshine duration is 1634.4–2153.0 h, the annual average temperature is 16.1 ℃, and the annual accumulated temperature is 4700–5162 ℃. The length of the frost-free period is 238–270 days. Annual rainfall is 1156.2–1688.7 mm. The research area is in a middle and lower mountainous area with yellow brown and yellow soils (Dong, 2016; Liu et al., 2019). *Pinus taiwanensis* is the dominant tree species in the community, accounting for about 40.45% of the trees of all species and accounting for more than 90% of the total biomass for all tree species. In the various sample plots, other tree species included, among other species, small numbers of *Quercus serrata*, *Toxicodendron succedaneum*, *Quercus acutissima* and *Dalbergia hupeana*.

2.2 Survey and sampling

The field survey was conducted in July 2016. The basic situation of vegetation in the tree layer, shrub layer and herb layer was investigated. For the trees (DBH⩾2.5 cm) in the tree quadrats, the surveyed items included tree species, tree height and DBH. Five 4 m×4 m shrub quadrats were set at the four corners and at the center of the tree quadrats to investigate shrubs (DBH<2.5 cm included). The shrub species, plant numbers, plant heights and average coverage were recorded. A 1 m×1 m herb quadrat was set randomly in each shrub quadrat to record herb species, coverage and abundance. Coverage refers to the ratio of area covered to total area for each species in the quadrat, and abundance refers to the number of species in the quadrat. The basic information for different plots is shown in Table 1.

2.3 Diameter class

Based on the growth characteristics of *Pinus taiwanensis*, the appropriate research methods for this species (Xing et al., 2019), the actual situation of the sample forest plots (the minimum DBH was 7.4 cm) and research operability, our diameter class scheme for *Pinus taiwanensis* trees had 9

Table 1 General status of sample plots of natural *Pinus taiwanensis* forests in Macheng

Plot No.	Elevation (m)	Longitude	Latitude	Slope (°)	Aspect	Canopy density	Forest density (trees ha^{-1})	Average DBH (cm)	Average height (m)	Average biomass (t ha^{-1})
1	792	115°17′23″	31°22′34″	20	Southeast	0.85	1425	22.479±10.114	13.913±3.942	296.097
2	812	115°18′50″	31°22′56″	15	North	0.70	1525	18.957±5.141	11.502±2.206	197.714
3	739	115°20'21	31°23'32	22	Northeast	0.65	1325	29.470±8.694	11.775±3.468	297.193
4	658	115°21′41″	31°23′25″	18	Southeast	0.80	1200	36.779±4.444	14.865±1.828	664.605

Note: 1, 2, 3 and 4 designate the four sample plots and this numbering will be used in the tables that follow.

classes: diameter class I covered trees with basal diameter <5 cm and height ≤1.5 m; for trees with the height >1.5 m, the diameter class was determined based on DBH step-lengths of 5 cm. The distribution of diameter classes of *Pinus taiwanensis* in forests of different ages was calculated. Trees with 5 cm<DBH≤10 cm were recorded as diameter class II; trees with 10 cm<DBH≤15 cm as diameter class III; the parameters for the other diameter classes of *Pinus taiwanensis* trees were calculated using the same 5 cm step scheme. The numbers of trees in each diameter class in the sample plots were counted. The diameter class was taken as the abscissa and the average density of *Pinus taiwanensis* trees in different diameter classes was taken as the ordinate, and a diameter class chart based on average density was created (Chao et al., 2015).

2.4 Analysis of species diversity

Species richness includes the following indicators:

Patrick index: S

Margalef index:

$$D_{ma} = \frac{S-1}{\ln N} \tag{1}$$

Menhinick index:

$$D_{mc} = \frac{S}{\sqrt{N}} \tag{2}$$

where S is the total number of species i in the quadrat, and N is the total number of all species.

Species diversity index includes the following indicators:

Shannon-Weiner index:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i \tag{3}$$

Simpson GINI index:

$$D = 1-\sum_{i=1}^{n} p_i^2 \tag{4}$$

Species evenness index includes the following indicators:

PieLou index:

$$E = -\frac{\sum_{i=1}^{n} p_i \ln p_i}{\ln S} \tag{5}$$

Alatalo index:

$$E_a = \frac{\left(\sum_{i=1}^{n} p_i^2\right)^{-1} - 1}{\exp\left(-\sum_{i=1}^{n} p_i \ln p_i\right) - 1} \tag{6}$$

where p_i is the proportion of the number of species i to the number of all species.

Species importance value of a tree layer:

$$IV_t(\%) = \frac{RA+RD+RF}{3} \times 100\% \tag{7}$$

Importance value of shrub and herb layers:

$$IV_s(\%) = \frac{RC+RH}{2} \times 100\% \tag{8}$$

$$IV_h(\%) = \frac{RC+RH}{2} \times 100\% \tag{9}$$

where $IV_t(\%)$, $IV_s(\%)$ and $IV_h(\%)$ represent important values of the tree layer, shrub layer and herb layer. RA refers to the ratio of the number of trees of a species to the total number of trees of all species; the RD value shows the ratio of the sectional area of a species at DBH to that of all species; RF refers to the ratio of the number of times a species occurred in recorded plots to the total number of times all species appeared. With respect to shrub and herb species, RC refers to the ratio of the coverage of a single species to the total coverage for all species; RH refers to the ratio of the height of a single species to the total height of all species. The parameter indexes of species importance, richness, diversity and evenness were calculated for each sample plot.

2.5 Similarities of species diversity

The effects of external disturbances on species composition in a community can be measured by an index for the similarities of species diversity. Greater similarities indicate less influence from disturbances to community species composition (Lin et al., 2019). We employed the Jaccard coefficient, Sørenson coefficient and Ochiai coefficient to compare the diversity similarities of different plots (Zhang et al., 2017), and compared the probability of similarity and dispersion of sample plots (Chen et al., 2018). The calculation formulas are as follows:

Jaccard coefficient:

$$C_j = \frac{t}{A+B-t} \tag{10}$$

Sǿrenson coefficient:

$$C_s = \frac{2t}{A+B} \tag{11}$$

Ochiai coefficient:

$$C_o = \frac{t}{\sqrt{t+A}\sqrt{t+B}} \tag{12}$$

where C_j, C_s and C_o are the similarity coefficients; t represents the number of species in common that two communities (or sample plots) being compared have; A and B represent the total number of species in the two communities or sample plots. $0.00<C\leqslant 0.25$ means great difference; $0.25<C\leqslant 0.50$ indicates moderate difference; $0.50<C\leqslant 0.75$ indicates moderate similarity; $0.75<C\leqslant 1.00$ shows great similarity of compared plots (Shen et al., 2010).

3 Results and analysis

3.1 Diameter class structure

The diameter class structure of *Pinus taiwanensis* trees in the sample plots is shown in Fig. 1. The ratio of *Pinus taiwanensis* trees in different diameter classes shows a bimodal distribution in the figure; that is, the diameter class structure has two relatively uniform wave peaks. The number of *Pinus taiwanensis* trees in diameter class I was 0, and only 2 trees (1.08% of the total) were in diameter class II. In diameter class III the number rose sharply to 27 (14.59% of the total), while diameter class IV had the greatest number of trees at 36 (19.46% of the total). The number then declined to 27 (14.59% of the total) in diameter class V, and in diameter class VI, the number dropped dramatically to 11 (5.95% of the total). In diameter class VII, the number of trees surged to a second peak of 35 (18.92% of the total), and then dropped to 34 (18.38% of the total) in diameter class VIII; only 13 trees (7.03% of the total) were recorded in diameter class IX. The biomass of *Pinus taiwanensis* in the sample plots decreased as average density increased (R=–0.904, P<0.05), indicating that forest density of *Pinus taiwanensis* may reflect the trend for the productive potential of a forest. The varying regularity of the numbers of *Pinus taiwanensis* trees with different diameters can be expressed with the following function:

$$y = 0.0288x^6 - 1.0219x^5 + 13.954x^4 - 92.283x^3 + 302.84x^2 - 441.8x + 218.56 \quad R^2 = 0.9179 \tag{13}$$

where y is diameter, x is the number of *Pinus taiwanensis* trees in different diameter classes.

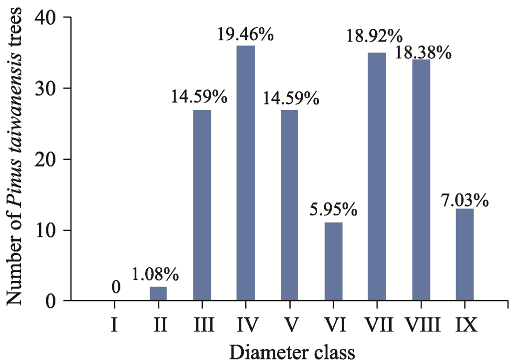

Fig. 1 The ratio of *Pinus taiwanensis* trees in different diameter class

3.2 Species composition under different forest densities

A total of 156 species of vascular plants belonging to 130 genera of 71 families were recorded in the four sample plots. The dominant families in the *Pinus taiwanensis* community were Compositae (11 genera and 15 species), Rosaceae (12 genera and14 species), Leguminosae (8 genera and 9 species), Euphorbiaceae (5 genera and 7 species) and Gramineae (5 genera and 5 species). Some less dominant families in the community included Rubiaceae (3 genera and 3 species), Caryophyllaceae (3 genera and 3 species), Anacardiaceae (3 genera and 3 species) and Vitaceae ((3 genera and 3 species). Both of the Rhamnaceae family and the Fagaceae family had 2 genera and 4 species; while 4 families, Asparagaceae, Ulmaceae, Apocynaceae and Cyperaceae, each had 2 genera and 3 species. Nine families each had 2 genera and 2 species and these are listed as follows: Liliaceae, Solanaceae, Scrophulariaceae, Iridaceae, Polygonaceae, Zingiberaceae, Betulaceae, Simaroubaceaeand and Celastraceae. The Violaceae family, the Dioscoreaceae family and the Primulaceae family each had 1 genera and 3 species; and 3 families, Aceraceae, Lauraceae and Cornaceae, each had 1 genera and 2 species. The remaining 41 species were members of 41 families and 41 genera.

3.3 Effects of forest density on species diversity

Under different forest densities of *Pinus taiwanensis* trees in the sample plots, the species diversity indexes of tree layers, shrub layers and herb layers changed significantly (Table 2, Fig. 2). As forest density increased, both the Patrick index S and the Margalef index D_{ma} for tree layers reached their maximums when forest density was 1425 trees ha^{-1}. When forest density was the greatest (1525 trees ha^{-1}), the average diameter was the smallest, but S, D_{ma} and Menhinick index D_{mc} were the lowest. When the average forest density was the lowest (1200 trees ha^{-1}), the diversity of the tree layer was the highest (Shannon index H'=1.6716; Simpson GINI index D= 0.7705). The change trends of E, the Alatalo index E_a and the two diversity indexes were basically the same.

As average density increased and average diameter decreased, the D_{ma} of the shrub layer first increased, then decreased and finally increased. When the average forest density reached its maximum (1525 trees ha^{-1}), the S reached the maximum value (27 species) and the D_{ma} was 5.4308. The D_{mc} of the shrub layer decreased with the increase of forest density, but the D_{mc} increased when forest density

Table 2 Species diversity of natural *Pinus taiwanensis* communities at different forest densities

Plot No.	Vegetation layer	Richness			Diversity		Evenness	
		Patrick (S)	Margalef (D_{ma})	Menhinick (D_{mc})	Shannon-Weiner (H')	Simpson GINI (D)	PieLou (E)	Alatalo (E_a)
1	Herb	14	2.3267	0.8568	1.7314	0.7618	0.6561	0.6879
	Shrub	16	2.9666	1.2769	2.1661	0.8266	0.7812	0.6170
	Tree	14	2.9839	1.5852	1.6215	0.6203	0.6144	0.4023
2	Herb	34	5.7461	1.9249	2.3669	0.8237	0.6712	0.4836
	Shrub	27	5.4308	2.4648	2.9612	0.9306	0.8985	0.7314
	Tree	9	1.7410	0.9045	1.4145	0.6369	0.6438	0.5631
3	Herb	32	5.8132	2.2242	3.0697	0.9853	0.9025	0.9593
	Shrub	22	4.3351	1.9522	2.5248	0.8673	0.8168	0.5687
	Tree	9	1.9384	1.1430	1.1886	0.5016	0.5410	0.4408
4	Herb	24	4.4244	1.7839	2.7411	0.9097	0.8625	0.6944
	Shrub	18	3.8577	1.9878	2.4750	0.8876	0.8563	0.7253
	Tree	12	2.0040	0.7714	1.6716	0.7705	0.6727	0.7768

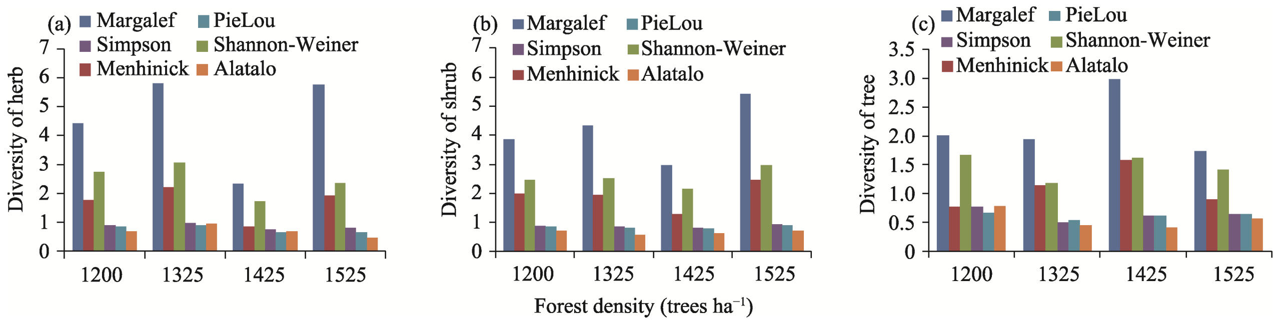

Fig. 2 Species diversities at different forest densities

reached its maximum, which was similar to the change of the S of shrub layers. The H' of shrub layers had a tendency to change by increasing-decreasing-increasing. The change trend of D in response to changes of forest density was consistent with that of D_{mc}. The change trend of E was consistent with that of H'. The E_a decreased first and then increased as forest density increased. At the maximum forest density (1525 trees ha^{-1}) when average tree diameter (DBH= 18.957±5.141 cm) was lowest, the richness, diversity and evenness of all shrub layers reached their maximum.

As forest density increased, the richness of the herb layer increased first, then decreased and finally climbed up again. The H' and the D of the herb layers showed a trend of increasing-decreasing-increasing, while both the D and the D_{mc} showed a trend of increasing-decreasing-increasing in response to the changes of forest density. The E first rose, then decreased and afterwards ascended again, while the E_a showed a trend of increasing-decreasing-descending as the forest density increased. When forest density was 1325 trees ha^{-1}, the richness, diversity and evenness of herb layers in the sample plots all reached their maximums.

3.4 Importance values at different forest densities

The importance values of plants in the four sample plots of *Pinus taiwanensis* in Macheng are listed below in Table 3. The importance value of *Pinus taiwanensis* was 63.10% in the fourth sample plot, while in other sample plots it was higher than 80.00%, indicating that *Pinus taiwanensis* was the dominant species in the tree layer and the forest was close to a pure forest. The dominant species varied significantly among the four shrub layers, while the importance values of shade tolerant herb *Rhododendron simsii* were in the first five components of the shrub layers in three sample plots. The highly adaptable shrub species *Lindera erythrocarpa* and *Lindera glauca* were the dominant species in the 2nd and the 3rd plots, while *Camellia sinensis* was observed to be the dominant species in forest gaps of two plots. The important values of *Camellia sinensis* changed dramatically, from a low of 4.54% to a high of 21.74%. *Lespedeza formosa* was the dominant shrub species in the fourth sample plot only. The dominant species in the herb layers showed slight changes from plot to plot. Among the dominant herb species were the shade tolerant species *Alpinia japonica*, *Oplismenus undulatifolius*, *Goodyera repens* and *Aster ageratoides,* and the highly adaptable species *Aristolochia mollissima* and *Anaphalis sinica*.

3.5 Comparison and analysis of similarities of diversity

To quantify the differences in diversity of the four sample

Table 3 The importance value of tree, shrub and herb species in the 4 sample plots

Plot No.	Tree species	IV_t(%)	Shrub species	IV_s(%)	Herb species	IV_h(%)
1	*Pinus taiwanensis*	84.33	*Rhododendron simsii*	34.72	*Oplismenus undulatifolius*	39.33
	Paulownia fortunei	2.17	*Camellia sinensis*	21.74	*Goodyera repens*	18.73
	Vernicia fordii	2.07	*Euscaphis japonica*	8.39	*Alpinia japonica*	15.73
	Diospyros lotus	1.72	*Wisteria sinensis*	6.63	*Aristolochia mollissima*	14.61
	Euscaphis japonica	1.57	*Alangium platanifolium*	5.19	*Viola verecunda*	3.75
	Celtis biondii	0.78	*Viburnum dilatatum*	4.40	*Parthenocissus dalzielii*	2.25
2	*Pinus taiwanensis*	81.84	*Lindera erythrocarpa*	22.31	*Polygonum hydropiper*	34.94
	Carya cathayensis	5.60	*Lindera glauca*	10.65	*Oplismenus undulatifolius*	19.23
	Quercus serrata	1.68	*Euscaphis japonica*	6.92	*Alpinia japonica*	8.33
	Symplocos paniculata	1.16	*Schisandra sphenanthera*	5.90	*Viola verecunda*	4.81
	Mallotus japonicus	0.70	*Corylus heterophylla*	5.88	*Teucrium viscidum*	4.49
	Lindera erythrocarpa	0.59	*Phyllanthus glaucus*	4.27	*Phryma leptostachya*	4.81
3	*Pinus taiwanensis*	81.12	*Rhododendron simsii*	38.61	Geum aleppicum	13.43
	Lindera glauca	6.69	*Lindera erythrocarpa*	12.87	*Kummerowia striata*	14.63
	Dalbergia hupeana	4.48	*Camellia sinensis*	11.88	*Erigeron annuus*	10.79
	Carya cathayensis	3.57	*Akebia trifoliata*	8.91	*Setaria faberii*	8.87
	Diospyros lotus	2.21	*Kerria japonica*	6.93	*Crassocephalum crepidioides*	6.71
	Castanea seguinii	1.76	*Lespedeza formosa*	5.94	*Fragaria nilgerrensis*	5.04
4	*Pinus taiwanensis*	63.10	*Lespedeza formosa*	15.85	*Anaphalis sinica*	20.44
	Quercus acutissima	15.79	*Lespedeza buergeri*	15.23	*Aster ageratoides*	12.71
	Quercus serrata	12.26	*Rhododendron simsii*	14.63	*Amphicarpaea edgeworthii*	8.84
	Dalbergia hupeana	4.20	*Glochidion wilsonii*	8.54	*Syneilesis aconitifolia*	8.29
	Albizia kalkora	2.31	*Elaeagnus pungens*	4.54	*Fragaria nilgerrensi*	5.65
	Quercus variabilis	1.32	*Rosa cymosa*	3.95	*Cyperus rotundus*	5.52

plots, an analysis of the similarities of diversity within the community was carried out. The indexes used to track similarities of diversity between any two plots were: Sørenson index C_s>Ochini index C_o>Jaccard index C_j. The three diversity similarity indexes showed the same change trends for comparisons of any two sample plots.

The four sample plots were aligned in a roughly straight line, and the distance between each of the plots was roughly the same. The shortest distance between two adjacent plots was 2.167 km, and the longest distance was 2.632 km. The greatest distance was between sample plot one and sample plot four (6.966 km). Therefore, the community similarity coefficients between any two adjacent sample plots were higher. The similarity coefficients are shown in Table 4, and it can be seen that there is a relative conformity between the similarity coefficient and the distance between the sample plots. The C_s of sample plot one and sample plot two (2.387 kilometers apart) was 0.5088, and this represented a medium similarity level. The similarity coefficient between sample plot two and sample plot three (2.632 km apart) was 0.4886, and that between sample plot three and sample plot four (2.167 km apart) was 0.4957, and these were very close to the medium similarity level. The similarity between sample plot one and sample plot four (6.966 km apart) was the lowest at 0.3265. The area of the *Pinus taiwanensis* community had the characteristics of a general regional habitat, and theoretically, the closer the distance, the lower the habitat heterogeneity (Chen et al., 2018). Although the species

Table 4 The diversity similarity indexes of 4 plots in the *Pinus taiwanensis* community

Plot No.	1			2			3		
	Jaccard (C_j)	Sørenson(C_s)	Ochiai(C_o)	Jaccard (C_j)	Sørenson(C_s)	Ochiai(C_o)	Jaccard (C_j)	Sørenson(C_s)	Ochiai(C_o)
2	0.3412	0.5088	0.3436						
3	0.2022	0.3364	0.2540	0.3232	0.4886	0.3284			
4	0.1951	0.3265	0.2469	0.2680	0.4228	0.2982	0.3295	0.4957	0.3319

similarity of neighboring habitats within a broader area of the community was relatively high, the diversity similarity coefficients between sample plot one and sample plot three (0.3364), between sample plot one and sample plot four (0.3265), and between sample plot two and sample plot four (0.4228) were relatively low, indicating medium diversity similarity differences.

4 Discussion

4.1 Diameter class structure and the forest succession trend

Tree size distribution is the most important and most basic element of forest structure, and the structure of tree size distribution can reflect the succession trend of a forest community (Lin et al., 2019). In this study, trees with average DBH were concentrated in diameter class IV and diameter class VII, a factor related to the time span of natural regeneration of *Pinus taiwanensis* forest after deforestation. As the forest ages, the number of trees in each diameter class per unit area gradually decreases, and the *Pinus taiwanensis* forest gradually develops into a purer artificial forest. Our survey did not identify any *Pinus taiwanensis* saplings in the understory. The forest was aging gradually, and this was accounted for by external interference and inappropriate forest management strategies.

4.2 Forest density and species composition

The average number of tree species in the *Pinus taiwanensis* community was small (11), and *Pinus taiwanensis* had predominant advantages in number and in diameter class structure. It was obvious that the community succession trend of *Pinus taiwanensis* progressed towards a community composed almost exclusively of *Pinus taiwanensis*. As the diameter class and canopy density increased in the sample plots, there were changes in the light intensity, humidity, soil nutrients and other conditions in the community, resulting in different understory microenvironments, species and distributions of shrub and herbs quantities (Wang et al., 2008). At the maximum density (1525 trees ha^{-1}), the average diameter was the lowest (DBH=18.957±5.141 cm), the canopy density was low (0.70), the numbers of species in both the shrub layer and the herb layer were greatest (24 and 34, respectively), and the diversity and evenness indexes were the highest. This indicates that an appropriate forest density can improve the species diversity of a community, and therefore, optimizing forest structure is conducive to the succession of natural forest communities (Fang et al., 2009).

4.3 Variations in the characteristics of species diversity

In general, diameter class structure affected undergrowth diversity, and light intensity affected species richness of regenerating undergrowth (Wang et al., 2008); extremely high density of a forest affected undergrowth diversity (Zhou et al., 2017). By controlling the humidity in the tree layer, forest density affected the growth and distribution of understory vegetation (Lei et al., 2003). In the research, the diversity and evenness of the herb layer were the highest when the canopy density was lowest, and at the same time, the diversity and evenness of the shrub layer were also higher. Therefore, canopy density was the main factor affecting plant diversity in the undergrowth layer of a natural forest (Rivaie, 2014). As diameter class changes during the process of community succession, canopy density increases, and light intensity in the community declines, both of which can lead to a decrease of species diversities of shrubs and herbs in the natural forest of *Pinus taiwanensis*.

As the *Pinus taiwanensis* forest developed towards a pure forest, the main understory shrub species were the shade-tolerant species *Rhododendron simsii*, and the highly-adaptable species *Lindera erythrocarpa* and *Camellia sinensis*. Both the abundance and diversity of the understory herb species were low, and the number of minor species was small, resulting in lower evenness. The dominant species in the herb layer were the shade-tolerant species *Alpinia japonica* and the highly-adaptable species *Aristolochia mollissima*. In terms of vertical structure, the diversity indexes were herb layer > shrub layer > tree layer, indicating that the herb layer required the least environmental resources, despite occupying a larger ecological niche. Once it had colonized the upper layer of the community, *Pinus taiwanensis* had the greatest potential to capture the light resources in the environment, and required the largest amount of other environmental resources, thus dominating the asymmetric competition in the community environment. Our research results revealed that the community structure of *Pinus taiwanensis* was the same as those of other light-demanding tree species (Yuan et al., 2017). Therefore, it is necessary to formulate appropriate management measures to adjust the density of *Pinus taiwanensis* forests, so as to improve the ecological functions of undergrowth vegetation, promote nutrient circulation and energy flow, gradually restore forest productivity, and protect species diversity (Jin et al., 2015).

4.4 Similarities of species diversity in the sample plots

Due to spatiotemporal differences and changes of ecological factors in different areas, habitat heterogeneity is formed, and this inevitably leads to differences in species composition and structure within a community (Zhen et al., 2019). On the elevation gradient, due to significant changes of environmental factors, the composition of plants in the community changed and different community structures came into being (Shen et al., 2010; Chen et al., 2018). The similarities of communities in adjacent habitats were often greater (Chen et al., 2018). However, the similarity coefficients between pairs of plots in the *Pinus taiwanensis* community ranged from 0.1951 to 0.5088, and the average sim-

similarity coefficient was 0.3356. This represents a medium level of dissimilarity, indicating that there were smaller habitat differences between different sample plots. The similarity coefficients demonstrated a relatively direct correspondence with the distance between different sample plots; that is, the longer the distance between any two sample plots, the lower the diversity similarity. However, the maximum distance between any two of the four sample plots was only 6.966 km, and the elevation variations between the plots were slight (658–812 m). It is, thus, difficult to explain the correlation between similarity coefficients and elevation changes. Therefore, disturbances and inappropriate management may be the main factors causing differences in diversity similarities between the four sample plots in the community.

5 Conclusions

During the restoration of natural secondary forest of *Pinus taiwanensis* in Macheng City, the species diversity in the understory gradually decreased as the diameter class structure of *Pinus taiwanensis* increased. A greater distance between two sample plots resulted in lower diversity similarity. The community structure was simple, and the succession trend of the Pinus taiwanensis forest was obviously towards a purer forest. Therefore, appropriate management measures should be taken that give consideration to forest density, or the diameter class of the forest and the characteristics of community structure. First, for large-diameter forests lacking a renewal layer, it is necessary to increase the proportion of small-diameter trees by supplementing the seedlings of *Pinus taiwanensis*, rationalizing the diameter class structure, and limiting the rate of aging of the present forest. Second, positive human intervention is needed to create "forest gaps." Doing so may improve the physiological conditions for small plants in ways that better the habitat for the ontogeny of the population renewal layer of *Pinus taiwanensis* and enhance natural regeneration ability (Wang et al., 2016). This can also promote species diversity with appropriate forest densities. Third, when the forest is close to maturity, unhealthy trees should be cut down to create a benign living environment for well-grown trees and to maintain the stable forest structure of *Pinus taiwanensis* (Pan et al., 2019).

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不同径级和密度下黄山松天然林物种多样性特征

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摘　要：黄山松是中国特有树种。为揭示黄山松天然林不同林龄径级结构与物种多样性特征，在麻城市黄山松天然次生林选择 4 个典型样地开展调查，研究黄山松径级结构与林分密度、群落物种多样性以及群落不同样地物种多样性相似性之间关系。结果表明：黄山松为群落优势种，在 IV 径级时，植株数量与全部植株比达到峰值，为 19.46%；在 VII 径级时该比值出现第二次峰值，为 18.92%；群落内维管植物 156 种，隶属于 71 科 130 属；林分平均密度最低时(1200 trees ha^{-1}, DBH=36.779±4.444 cm)，乔木层多样性(H'=1.6716)和均匀度(E=0.6727)最高；在林分平均密度最高时(1525 trees ha^{-1}, DBH=18.957±5.141 cm)，灌木层丰富度(D_{ma} = 5.4308)、多样性(H' = 2.9612)和均匀度最高(E = 0.8985)。在林分密度为 1325 trees ha^{-1} 时，草本的丰富度(D_{ma} = 5.8132)、多样性(H' = 3.0697)和均匀度(E = 0.9025)达到最大值。垂直结构上 α 多样性指数为：草本层>灌木层>乔木层；郁闭度增高会减弱群落林分内光照强度，造成黄山松群落内灌、草层物种多样性下降；样地间平均相似性系数为 0.3356，处于中等不相似水平；干扰因子和不当管理可能是造成群落内不同样地存在较大的生境差异的主要原因。因此，必须制定科学的经营管理措施，优化黄山松林分结构，创造良好的群落环境，以提高物种多样性和稳定森林群落结构。

关键词：黄山松；径级；林分密度；物种多样性