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ORIGINAL RESEARCH ARTICLE

The relationship between species diversity and tree growth in natural secondary forests in Northeast China

Ye Luo[1,2], Huaijiang He[1,2], Zhonghui Zhang[1,2*], Ting Liu[1,2], Jingqi Yuan[1,2], Zhongliang Yu[1,2], Guangdao Bao[1,2], Dawei Zhang[1,2]

[1] *Jilin Provincie Academy of Forestry Science, Chang-chun 130033, Jilin, China. E-mail: zzhgiszzh@163.com*

[2] *Interregional Cooperation Science and Technology Innovation Center for Restoration and Reconstruction of Degraded Forest Ecosystem in Jilin Province, Changchun 130033, Jilin, China.*

ABSTRACT

[Objective] To understand the relationship between species diversity and tree growth in natural secondary forests in Northeast China, to determine the reasonable size of species diversity, and to carry out appropriate nurturing harvesting and artificial replanting, so as to provide a scientific and theoretical basis for secondary forest management and management. **[Methods]** A total of 123 sample plots were set up in the Xiaoxinganling (XXAL), Zhangguangcailing (ZGCL), Laojialing (LYL), Changbai Mountain (CBS), Hadaling (HDL) and Longgang Mountain (LGS) areas in Northeast China, they were used to investigate the species composition, importance value, diversity and tree growth in each area. **[Results]** A total of 48 species belonging to 17 families and 31 genera were investigated in all the sample plots, among which the sample plots in Longgang Mountain contained the largest number of families, genera and species, followed by Hada Ling, Changbai Mountain, Laoyaling, Zhangguangcai Mountain and Xiaoxinganling. The α-diversity index of species in the sample sites was the largest in Changbai Mountain and the smallest in Xiaoxinganling, and the difference between them was significant ($P < 0.05$), while the richness index was the largest in Longgang Mountain and the smallest in Xiaoxinganling. The difference between them was significant ($P < 0.05$), while the greater the difference in latitude between the regions, the more obvious the difference in β-diversity index of species in the sample sites, and the fewer species shared between the two regions. The higher the rate of community succession, the higher the average diameter at breast height and the average tree height in each region were CBS > LYL > LGS > ZGCL > HDL > XXAL. The largest breast tree species in each region was Mongolian oak in Changbai Mountain with a diameter at breast height of 64.8 cm, and the smallest breast tree species in each region was Tyrannus sylvestris in Longgang Mountain with a diameter at breast height of 4.0 cm. The highest tree species in each region was Liriodendron sylvestris in Longgang Mountain with a height of 28.9 m, and the smallest species is yellow pineapple with a height of 1.3 m in Longgang Mountain. **[Conclusion]** Within a certain range, species diversity has a facilitating effect on the average diameter at breast height and average tree height of species within a stand. Therefore, during the management of secondary forests, appropriate nurturing harvesting and artificial replanting should be adopted to ensure reasonable species diversity in the stands and provide optimal space for the growth of natural secondary forests.

Keywords: Natural Secondary Forest; Species Composition; Importance Value; Species Diversity; Tree Height; Diameter at Breast Height

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1. Introduction

Since the 20th century, with anthropogenic activity disturbance and destruction of primary forests, natural secondary forests in China have accounted for half of the total forest area[1], especially in northeast China, natural secondary forests have become the main forest stand type, so conducting experiments related to natural secondary forests has become an important research content today. Although most scholars have researched natural secondary forest community composition, structure, diversity, biomass, and ecosystem function[2-6], fewer studies have been conducted on the relationship between species diversity and tree growth

in natural secondary forests on a large regional scale in Northeast China.

The study of the relationship between species diversity and tree growth is a fundamental issue in ecology[7], and the relationship between the two is one of the more studied issues in ecology, including the relationship between species diversity and diameter at breast height, tree height, biomass and productivity[8]. Studying the interrelationships is essential for understanding the mechanisms of global species diversity[9].

Species diversity research is currently focused on the relationships between species diversity and biomass and productivity[10-13], the effects of environmental factors on species diversity at different altitudes and latitudes[14,15], the effects of anthropogenic disturbances on species diversity and functional diversity[16,17], and the spatial pattern distribution of species diversity[18]. Related studies have been relatively systematic and extensive. However, there are relatively few studies on the relationship between species diversity and tree growth in forest ecosystems[19]. And they mainly focus on small-scale and homogeneous habitats, which ignore the influence of large-scale and spatial heterogeneity on the relationship between species diversity and tree growth. Meanwhile, the ecosystems in forest stands are affected by many factors, and it is impossible to limit all experimental factors at the same time, resulting in the current conclusions on the relationship between species diversity and tree growth in forest stands. The relationship between species diversity and tree growth in forest stands is not uniformly concluded[20]. Therefore, it is important to focus on the relationship between species diversity and tree growth in a large region of Northeast China.

There are three main spatial scales of diversity indices: α diversity, β diversity, and γ diversity[21]. Each spatial scale has different environments and different measured data. A diversity is currently the most studied biodiversity[4,13,22]. A diversity is mainly concerned with the number of species in a local homogeneous habitat, and is therefore also referred to as intra-habitat diversity. B diversity is mainly the variation along environmental gradients, the similarity of species composition between different habitat communities or the turnover rate of species along environmental gradients and is also It is also known as interhabitat diversity, and this study is one of the current research hotspots[23,24]. Γ diversity describes the diversity at regional or continental scales, and refers to the number of species at regional or continental scales, and is also known as regional diversity, and because it is relatively difficult to study under continental scale regions, current studies are conducted at small scales, so γ diversity studies are relatively rare.

In this study, in order to investigate the relationship between species diversity and tree growth in natural secondary forests in northeast China, we applied α-diversity and β-diversity to analyze the species composition, structural characteristics, and latitudinal gradient, which can provide scientific basic information for natural secondary forest management and management in northeast China. At the same time, by determining a reasonable size of species' diversity and conducting appropriate nurture harvesting, we can improve the growth conditions of the forest through appropriate felling and harvesting or artificial replanting.

2. Overview of the study area

The northeastern region has a temperate continental monsoon climate from south to north.

It has four distinct seasons and a relatively high latitude, with cold and long winters and warm and short summers, and is mainly a humid and semi-humid region. The vegetation types in the three northeastern provinces belong to the Changbai Mountain flora, and the main tree species are *Liriodendron juglans mandshurica, Fraxinus mandshurica, Phellodendron amurense, Quercus mongolica, Tilia mongolica, Tilia mandshurica, Fraxinus rhynchophylla, Ulmus pumila, Ulmus laciniata, Tilia mandshurica, Ulmus rhynchophylla, Ulmus pumila, Ulmus laciniata, Tilia mandshurica. Amurensis, Tilia mandshurica, Fraxinus rhynchophylla, Ulmus pumila, Ulmus laciniata, Carpinus cordata, Acer mono, Acer pseudosieboldi pseudosieboldianum, Syringa reticulata, Prunus padus, Rhamnus davurica, Betula platyphylla, Betula costata, Betula davurica, Populus Populus davidiana, Populus ussuriensis, Albizia kalkora, Maackia*

amurensis, Acer mandshuricum, Acer triflorum, Alnus sibirica, Pinus koraiensis, Pinus sibirica, Pinus sibirica, Pinus sibirica, Pinus koraiensis. Pinus koraiensis, sand pine Abies holophylla, camphor pine Pinus sylvestris, bristlecone pine Abies nephrolepis, and *larch Larix gmelinii*.

This research studied a comprehensive survey of natural secondary forest tree species in the areas of Xiaoxinganling (I), Zhangguangcailing (II), Laojialing (III), Changbai Mountain (IV), Hadaling (V) and Longgang Mountain (VI) (123°58'13"–130°24'10"E, 40°52'25"–46°48'50"N) from 2017 to 2019 according to the distribution of mountain systems and latitudes (**Figure 1**).

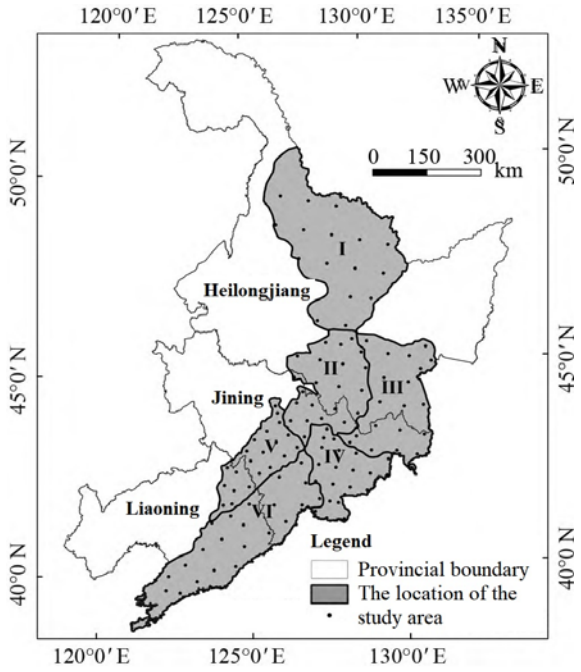

Figure 1. Plot distribution.

3. Experimental methods

3.1 Sample plot setting

In the six areas, sample points were evenly distributed in each area according to the geographic grid, and sample plots were set up by the sample circle method at the sample points already laid out. That is at a distance of more than 20 m from the forest edge, a circular sample plot was established with a point as the center and 17.85 m as the radius without crossing rivers, roads or logging lines. All trees with diameter at breast height of about 5 cm and above within the sample circle were surveyed and registered respectively. The main survey contents included species name, diameter at breast height, tree height, crown width (S–N, W–E), angle and distance from the center of the circle, etc. The longitude, latitude, elevation, slope, slope direction, slope position, soil depth and humus layer depth of each sample plot were also recorded.

3.2 Species diversity measurement

3.2.1 Importance value (IV)

$$IV = (RD_i + RF_i + RP_i)/3 \quad (1)$$

Where, RD_i is the relative density of species i, RF_i is the relative frequency of species i, and RP is the relative significance of species i.

3.2.2 Species diversity

Species diversity is an important measure of the functional complexity and stability of communities and mainly includes α diversity index, β diversity index and γ diversity index[21]. A diversity index (Shannon-Wiener diversity index H', Simpson diversity index D and Pielou evenness index J_{sw}), β diversity index (Sφrensen β diversity index βs and Cody diversity index βc) and species richness (Margalef richness index R) were evaluated together.

$$H' = -\sum_{i=1}^{n} P_i \ln P_i \quad (2)$$

$$D = 1 - \sum_{i=1}^{n} P_i^2 \quad (3)$$

$$J_{sw} = \left(-\sum_{i=1}^{n} P_i \ln P_i \right) / \ln S \quad (4)$$

$$\beta s = 1 - 2c/(a+b) \quad (5)$$

$$\beta c = [g(H) + l(H)]/2 \quad (6)$$

$$R = (S-1)/\ln N \quad (7)$$

Where: $P_i = N_i/N$, P_i is the relative importance values of species, N is the sum of the importance values of each species in the sample site where species i is located. N_i is the importance value of the i^{th} species. S is the total number of species in the sample site. a and b are the number of all species in the two communities, c is the number of species

shared between communities. g(H) is the number of species increasing along the habitat gradient H. l(H) is the number of species lost along the habitat gradient H, i.e., the number of species present in the previous gradient but absent in the next gradient. N is the total number of individuals in the sample plot.

3.3 Data analysis

Experimental data and table creation were organized using Excel 2007 software, while data were analyzed and compared using SPSS 19.0 software and plotted using sigmaplot 12.0 software.

4. Results and analysis

4.1 Species composition and diversity

The species composition of natural secondary forests in different areas was investigated (**Table 2**), and 48 species belonging to 17 families and 31 genera were investigated in all sample sites, including 19 species belonging to 13 families and 17 genera in the Xiaoxinganling area. The importance values were 22.88%, 18.34%, 16.72%, 8.37% and 7.95%, and the total importance values were more than half, which were the dominant species. Thirty species were investigated in the sample site of Zhang Guangcai Ridge, belonging to 13 families and 19 genera, and 13 species with importance values ≥2. The top five species were Maple, Elm, Liriodendron, Ash and Red Pine, with importance values of 29.98%, 11.07%, 10.70%, 4.49% and 4.38%, respectively, which were more than half of the total importance values and were the dominant species. There were 28 species belonging to 14 families and 20 genera, and 14 species with importance value ≥2. Red pine, linden, larch, lupine and elm ranked in the top five with importance value of 23.16%, 15.52%, 7.66%, 6.31% and 6.22% respectively, and the total importance value was more than half, which were the dominant species. The sample site in Changbai Mountain area surveyed 28 species belonging to 15 families and 22 genera, 14 species with species importance value ≥2. Tyrannus sylvestris, Acer sylvestris, Elm, Acacia sylvestris and Linden ranking in the top five with importance values of 22.81%, 11.70%, 8.69%, 8.05% and 6.73% respectively, with a total importance value of more than 50%, which are the dominant tree species. There were 29 species belonging to 15 families and 22 genera in the Haddaling area, and 14 species with importance value ≥2. The top five species were Maple, Elm, Mongolian oak, Quercus alba and Liriodendron, with importance values of 37.16%, 9.56%, 8.10%, 5.12% and 4.28% respectively, and more than half of them were dominant. There are 39 species in the Longgang Mountain sample area, belonging to 15 families and 27 genera, with 13 species with importance value ≥2. The top five species in importance value are Maple, Elm, Mongolian oak, Quercus alba and Liriodendron, with importance value size of 27.04%, 9.21%, 7.73%, 6.46% and 4.39%, respectively, and more than half of the total importance value is dominant. Overall, the dominant species in each region were mainly elm, colored maple and water willow.

The α-diversity (Shannon-Wiener diversity index H', Simpson diversity index D and Pielou evenness index Jsw) and richness (Margalef richness index R) of species in natural secondary forest sample plots in different regions were determined (**Table 3**).

The Shannon-Wiener index (H') was the largest in Changbai Mountain and the smallest in Xiaoxinganling. The difference between them was significant ($P < 0.05$). The Shannon-Wiener index

Table 1. Basic situation of plots

Variables	XXAL	ZGCL	LYL	CBS	HDL	LGS
Number of sample	16	22	20	22	21	22
Number of family	13	13	14	15	15	15
Number of genus	17	19	20	22	22	27
Number of species	19	30	28	28	29	39
Stand density/(plan·hm^{-2})	619	590	551	605	582	610
Latitude/(°)	46°16’15”–46°48’50”	43°2’10”–46°03’03”	42°48’56”–45°59’41”	41°19’36”–43°32’29”	41°57’11”–43°08’01”	41°02’10”–42°56’51”
Altitude/m	308–401	230–495	312–577	437–834	397–723	257–815
Soil depth/cm	15.6–47.0	7.5–56.0	11.5–46.8	5.2–32.0	7.6–31.3	15.6–34.2
Humus thickness/cm	8–16	4–35	5–14	7–23	6–21	8–18

Table 2. Tree species of important values ≥2 in different areas

XXAL		ZGCL		LYL		CBS		HDL		LGS	
Species	Important value /%	Species	Important value /%	Species	Important value /%	Species	Important value /%	Species	Important value /%	Species	Important value /% Species Important value /%
U. Pumila	22.88	*A. Mono*	29.98	P. Koraiensis	23.16	S. Reticulata	22.81	*A. Mono*	37.16	*A. Mono*	27.04
P. Koraiensis	18.34	*U. Pumila*	11.07	Z awwre/w/s	15.52	*A.mono*	11.70	*U.pumila*	9.56	*U.pumila*	9.21
F. Mandshurica	16.72	J. Mandshurica	10.70	L. Gmelinii	7.66	U. Pumila	8.69	Q. Mongolica	8.10	Q. Mongolica	7.73
S. Reticulata	8.37	F. Mandshurica	4.49	S. Reticulata	6.31	A. Kalkora	8.05	F. Mandshurica	5.12	K mandshurica	6.46
J. Mandshurica	7.95	P. Koraiensis	4.38	U. Pumila	6.22	T. Amurensis	6.73	J. Mandshurica	4.28	A. Triflorum	4.39
A. Holophylla	4.04	S. Reticulata	4.14	J. Mandshurica	5.60	J. Mandshurica	5.58	U. Laciniata	3.84	J. Mandshurica	4.35
L. Gmelinii	3.66	P- amurense	3.76	T. Mandshurica	4.65	*F. Mandshurica*	5.51	Lime*t. Amurensis*	3.30	*T. Amurensis*	4.22
P. Padus	3.09	T. Amurensis	3.38	A. Mono	4.55	U. Laciniata	4.27	L. Gmelinii	3.08	F. Rhynchophylla	3.94
P. Amurense	2.95	A. Mandshuricum	3.29	F. Mandshurica	4.21	A. Triflorum	3.21	A. Mandshuricum	2.95	A. Mandshuricum	2.94
A. Mono	2.57	*Q. Mongolica*	2.94	P. Amurense	2.65	P. Amurense	2.90	P. Amurense	2.37	P. Amurense	2.88
T. Amurensis	2.57	U. Laciniata	2.64	P. Padus	2.50	A. Sibirica	2.69	P. Padus	2.33	A. Pseudosieboldianum	2.85
R. Davurica	2.15	T. Mandshurica	2.49	A. Mandshuricum	2.26	A. Mandshuricum	2.61	P. Sylvestris	2.03	C. Cordata	2.64
-C. Cordata 2.64	-C. Cor data	C. Cor data	2.27	Fp A. Holophylla	2.12	*Q. Mongolica*	2.09	*F. Rhynchophylla*	2.03	*L. Gmelinii*	2.23
-	-	- -	- -		2.08	P. Koraiensis	2.03	P. Ussuriensis	- -	-P. Ussuriensis	-Total
Total	95.30	- - - - Total 95.30	85.50	-Total	89.46	-	88.90	-	86.18	-	80.89

(*H'*) of species in Laozi Mountain, Longgang Mountain, Zhangguangcai Mountain and Hada Mountain was located between that of Changbai Mountain and Xiaoxinganling, and it was not significantly different from species in Changbai Mountain but was significantly different from species in Xiaoxinganling ($P < 0.05$). Simpson's diversity index (*D*) was the largest in Changbai-Mountain and the smallest in Xiaoxinganling, and the difference between them was significant ($P < 0.05$), followed by Laoyanling, Longgang Mountain, Zhangguangcai Mountain and Hada Mountain, and the species diversity index in Longgang Mountain and Zhangguangcai Mountain area was in the middle region, and it was not significantly different from other areas. The Pielou evenness index (*Jsw*) was the largest in Changbai Mountain, followed by Laozi Mountain, Longgang Mountain, Zhangguangcai Mountain and Hada Mountain, and the smallest in Xiaoxingan Mountain, and there was no significant difference between the regions. The Margalef richness index (*R*) was the largest in Longgang Mountain and the smallest in Xiaoxinganling, and the difference between them was highly significant ($P < 0.05$), and the species diversity was not significantly different between the rest of the regions, but all of them were significantly different from Longgang Mountain and Xiaoxinganling ($P < 0.05$).

Table 4 statistical analyzed the species *β*-diversity (Sφrensen diversity and Cody diversity) within natural secondary forest sample plots in different regions. It revealed that there were mainly latitudinal differences between regions. Sφrensen diversity indices range from 0.1724 to 0.2681 in the range from high latitude areas in the

Table 3. α diversity of species in different areas

Index	XXAL	ZGCL	LYL	CBS	HDL	LGS
Shannon-Wiener (H')	2.3197 ± 0.08^{b}	2.6413 ± 0.06^{a}	2.6817 ± 0.08^{a}	2.6950 ± 0.07^{a}	2.5026 ± 0.05^{a}	2.6657 ± 0.06^{a}
Simpson (D)	0.7378 ± 0.04^{b}	0.7766 ± 0.03^{ab}	0.8048 ± 0.01^{a}	0.8373 ± 0.03^{a}	0.7432 ± 0.03^{b}	0.7822 ± 0.02^{ab}
Pielou (J_{sw})	0.8457 ± 0.02^{a}	0.8728 ± 0.01^{a}	0.8957 ± 0.03^{a}	0.9021 ± 0.01^{a}	0.8638 ± 0.03^{a}	0.8753 ± 0.03^{a}
Margalef (R)	2.8002 ± 0.06^{c}	3.8289 ± 0.05^{b}	3.9458 ± 0.07^{b}	4.0698 ± 0.04^{b}	4.2750 ± 0.05^{b}	5.1511 ± 0.03^{a}

†Different lowercase letters in the same row indicate significant differences in species diversity in different areas (P<0.05).

Xiaoxinganling to low latitude areas in the Longgang Mountains. Sφrensen diversity indices ranging from 0.1724 to 0.2681 between species in the Xiaoxinganling. On the contrary, the Sφrensen diversity index was the smallest between Laozi Ridge and Zhangguangcai Ridge, and the most species were shared between the two areas. In addition, the Cody diversity index increased with decreasing latitude gradient, and the lower the latitude, the greater the Cody diversity, indicating the higher the community succession rate.

4.2 Species community characteristics

Table 5 analyzed species diameter at breast height and tree height in the natural secondary forest sample plots of different regions. We found that the average diameter at breast height of species in Changbaishan region was the largest with 17.1 cm, followed by Laoyan Ridge, Longgang Mountain Zhangguangcai Ridge and Hada Ridge. The average diameter at breast height in Xiaoxingan Ridge was the smallest with 15.0 cm, and the largest species at breast height in each region was Mongolian oak in Changbaishan region with a diameter at breast height of 64.8 cm. The species with the smallest diameter at breast height was Mongolian oak in the Longgang Mountains with a diameter at breast height of 4.0 cm. In terms of tree height, the largest average tree height was in Changbai Mountain with a mean height of 15.5 m, followed by Laojialing, Longgang Mountain, Zhangguangcai Mountain, and Hada Mountain, and the smallest average tree height was in Xiaoxinganling with 11.1 m. The largest tree height species in each region was Liriodendron hirsutum in Longgang Mountain with a height value of 28.9 m, and the smallest tree height species was yellow pineapple in Longgang Mountain with a height value of 1.3.

Table 6 analyzed the diameter at breast height and height of the top 5 tree species in different regions. It was found that elm was distributed in large

Table 4. β diversity of species in different areas

Area	XXAL	ZGCL	LYL	CBS	HDL	LGS
XXAL	-XXAL	0.1853	0.1936	0.2156	0.2384	0.2681
ZGCL	6.0	-ZGCL	0.1724	0.2414	0.2358	0.2634
LYL	6.0	7.5	-0.2453	0.2453	0.2498	0.2583
CBS	7.0	8.0	7.5	-7.5	0.1963	0.2318
HDL	7.5	8.0	8.5	7.0	-0.2059	0.2059
LGS	7.5	8.5	8.5	7.5	8.0	-

†The upper right corner is the Sφrensenβdiversity index, and the lower left corner is the Codyβdiversity index.

Table 5. DBH and tree height of tree species in different areas

Area	Mean	Min	Max	Mean	Min	Mean Min
XXAL	15.0	4.8	63.6	11.1	1.8	26.8
ZGCL	16.8	4.3	62.2	14.3	2.2	27.8
LYL	17.0	5.0	63.7	15.4	2.6	27.7
CBS	17.1	4.6	64.8	15.5	2.4	27.1
HDL	16.4	5.0	61.4	13.0	2.2	28.1
LGS	16.9	4.0	628	14.8	1.3	28.9

Table 6. DBH and tree height of the top 5 important values trees species in different areas

XXAL			ZGCL			LYL		
Species	Mean DBH/cm	Mean Height/m	Species	Mean DBH/cm	Mean Height/m	Species	Mean DBH/cm	Mean Height/m
U. Pumila	13.28	10.15	A. Mono	15.10	11.09	P. Koraiensis	19.11	12.38
P. Koraiensis	10.73	7.78	U. Pumila	14.18	11.08	T. Amurensis	14.51	10.80
F. Mandshurica	16.76	15.44	J. Mandshurica	12.35	10.78	L. Gmelinii	20.33	17.25
S. Reticulata	6.31	5.59	F. Mandshurica	16.45	14.64	S. Reticulata	7.89	6.41
J. Mandshurica	10.46	9.56	P. Koraiensis	10.81	7.28	U. Pumila	13.29	9.98
	CBS			HDL			LGS	
Species	Mean DBH/cm	Mean Height/m	Species	Mean DBH/cm	Mean Height/m	Species	Mean DBH/cm	Mean Height/m
S. Reticulata	8.93	6.63	A. Mono	11.77	10.65	A. Mono	11.59	9.73
A. Mono	12.41	8.39	U. Pumila	11.89	9.05	U. Pumila	14.24	11.28
U. Pumila	11.79	7.53	Q. Mongolica	25.33	17.85	Q. Mongolica	18.18	13.5
A. Kalkora	12.83	9.14	F. Mandshurica	19.65	18.58	F. Mandshurica	18.90	15.97
T. Amurensis	13.94	10.81	J. Mandshurica	14.89	12.61	A. Triflorum	14.34	12.11

Table 7. Relationship between species diversity (x) and mean DBH (y) in each region

Area	Shannon-Wiener (H')	Simpson (D)	Pielou (Jsw)	Margalef (R)
	$y = -29.0352 + 38.7745x$	$y = -31.1462 + 68.5300x$	$y = -54.2821 + 111.1314x$	$y = -2.9016 + 16.0765x$
XXAL	$-7.9027x^2$	$-42.3019x^2$	$-62.6278x^2$	$-2.0805x^2$
	$R^2 = 0.9753$	$R^2 = 0.5443$	$R^2 = 0.8924$	$R^2 = 0.9705$
	$y = -64.589 + 86.2756x$	$y = -89.3564 + 146.8567x$	$y = -88.6529 + 158.3649x$	$y = -78.5631 + 115.6425x$
ZGCL	$-16.5986x^2$	$-90.6528x^2$	$-88.6498x^2$	$-14.2389x^2$
	$R^2 = 0.9625$	$R^2 = 0.8523$	$R^2 = 0.9152$	$R^2 = 0.8946$
	$y = 25.8964 + 59.8748x$	$y = 116.3528 + 258.6492x -$	$y = 96.5849 + 186.5467x$	$y = 6.3916 + 18.6942x$
LYL	$-10.6919x^2$	$159.6658x^2$	$-104.8743x^2$	$-2.5951x^2$
	$R^2 = 0.8735$	$R^2 = 0.8527$	$R^2 = 0.9028$	$R^2 = 0.7437$
	$y = 108.5679 + 235.2854x$	$y = 98.6431 + 198.6428x$	$y = 48.6792 + 123.8216x$	$y = 35.4689 + 72.5691x$
CBS	$-40.5664x^2$	$-122.6856x^2$	$-65.8127x^2$	$-8.8627x^2$
	$R^2 = 0.9134$	$R^2 = 0.7394$	$R^2 = 0.8582$	$R^2 = 0.9226$
	$y = 56.4628 - 105.6482x$	$y = 62.8564 + 98.4567x -$	$y = 59.6243 + 110.6943x$	$y = 28.6913 + 68.9643x$
HDL	$+27.8022x^2$	$60.7759x^2$	$-62.1886x^2$	$-8.4106x^2$
	$R^2 = 0.8546$	$R^2 = 0.7945$	$R^2 = 0.9213$	$R^2 = 0.8533$
	$y = 82.3492 + 162.5492x$	$y = 105.8694 + 186.5943x -$	$y = 137.4961 + 187.3694x$	$y = 92.4682 + 173.3346x$
LGS	$-30.1017x^2$	$115.4698x^2$	$-105.2679x^2$	$-21.1382x^2$
	$R^2 = 0.8992$	$R^2 = 0.9053$	$R^2 = 0.9017$	$R^2 = 0.8941$

numbers in all regions and was the main tree species, and the average diameter at breast height and height of elm, color wood maple, water willow and hoodia were basically the same in all regions with no significant differences. While red pine showed some differences in each region, with larger values of diameter at breast height and height of red pine in Laozi Ridge, and smaller values in Xiaoxinganling and the average diameter at breast height and the average height of red pine in each region are small, and the red pine is in the stage of natural regeneration.

4.3 Relationship between species diversity and diameter at breast height and tree height

4.3.1 Relationship between species diversity and diameter at breast height and tree height in a single area

Tables 7 and 8 compared the species diversity with mean diameter at breast height and mean height of tree species in the sample plots of individual areas. It showed that the relationship between α diversity and richness of each species and mean diameter at breast height of tree species in the remaining areas showed a single-peaked curve except for the Shannon-Wiener diversity index in the Haddaling area, i.e., with increasing α diversity and richness, the mean diameter at breast height of tree species in the sample plots. In addition, the R^2 values of α diversity and richness were above 0.70 in all regions except for the smaller R^2 value of Simpson's diversity index in the Xiaoxinganling region, which was a good fit. In general, the alpha diversity of species within the sample plots in each area had a positive effect on the growth of tree species at breast height within the stand.

Table 8 showed that the relationship between α diversity and richness of species and the average tree height of tree species in all regions showed a single-peaked curve except for the Shannon-Wiener diversity index in Xiaoxinganling and Hadaling. The average height of tree species in the sample site showed a trend of first increasing and then decreasing with the increasing α diversity and richness, and there was a maximum value at a specific value. The R^2 values of α diversity and richness in each area were above 0.69, which was a good fit.

4.3.2 Relationship between species diversity and diameter at breast height and tree height in all areas

Figure 2 and **3** found the trends of species diversity in relation to the mean diameter at breast height and mean tree height of tree species within the sample plots in all areas. The mean diameter at breast height of tree species within the sample

Table 8. Relationship between species diversity (x) and average tree height (y) in each region

Area	Shannon-Wiener (*H'*)	Simpson (*D*)	Pielou (*Jsw*)	Margalef (*R*)
XXAL	$y = 48.6972 - 91.2576x$ $+17.2564x^2$ $R^2 = 0.8943$	$y = 111.6943 + 289.6143x$ $-176.5946x^2$ $R^2 = 0.9191$	$y = 195.2618 + 364.8954x$ $-200.5461x^2$ $R^2 = 0.8463$	$y = 26.5916 + 68.5317x$ $-8.1564x^2$ $R^2 = 0.8229$
ZGCL	$y = -69.3162 + 123.1218x$ $-23.8128x^2$ $R^2 = 0.9152$	$y = -88.9134 + 176.8259x$ $-107.8216x^2$ $R^2 = 0.8391$	$y = -134.2256 + 302.2561x$ $-166.0745x^2$ $R^2 = 0.7539$	$y = -55.9127 + 87.3189x$ $-10.3954x^2$ $R^2 = 0.6939$
LYL	$y = 105.2141 + 203.2581x$ $-38.5529x^2$ $R^2 = 0.9088$	$y = 216.5943 + 346.1678x$ $-211.0825x^2$ $R^2 = 0.8716$	$y = 456.3258 + 756.3215x$ $-415.2364x^2$ $R^2 = 0.9341$	$y = 62.8916 + 99.3387x$ $-11.8207x^2$ $R^2 = 0.7988$
CBS	$y = 168.8829 + 259.3349x$ $-48.5961x^2$ $R^2 = 0.8164$	$y = 208.9437 + 425.6179x$ $-259.2456x^2$ $R^2 = 0.7966$	$y = 391.2546 + 660.2518x$ $-362.7756x^2$ $R^2 = 0.9022$	$y = 69.8520 + 125.3394x$ $-14.9213x^2$ $R^2 = 0.9006$
HDL	$y = -125.9438 - 208.5691x$ $+39.6489x^2$ $R^2 = 0.9561$	$y = -188.2679 + 312.1649x$ $-189.4628x^2$ $R^2 = 0.9316$	$y = -221.3566 + 450.4169x$ $-247.9648x^2$ $R^2 = 0.8989$	$y = -81.2953 + 144.7749x$ $-17.2569x^2$ $R^2 = 0.8564$
LGS	$y = 99.6482 + 196.5219x$ $-37.1259x^2$ $R^2 = 08886$	$y = 113.3125 + 166.3314x -$ $101.4215x^2$ $R^2 = 0.8006$	$y = -334.8567 + 524.4893x$ $-288.1802x^2$ $R^2 = 0.7781$	$y = 72.1438 + 119.6874x$ $-14.2485x^2$ $R^2 = 0.8317$

plots all showed an overall trend of increasing and then decreasing with increasing species diversity and species richness. It is that the mean diameter at breast height of tree species within the sample plots showed a single-peaked curve in relation to α diversity index and species richness. It is that the average diameter at breast height of tree species in the stand increased and then decreased with the increase of α diversity index and species richness within a certain range. The average diameter at breast height of tree species showed a quadratic relationship with α-diversity index and species richness with R^2 of 0.9894, 0.7808, 0.9973 and 0.8454 respectively, which were well fitted. The average diameter at breast height of tree species reached the maximum value at 2.7985, 0.8137, 0.8917 and 4.5587 for the Shannon-Wiener diversity index, Simpson diversity index, Pielou evenness index and Margalef richness index, respectively, through the fitting calculation. Overall, the species diversity has a positive effect on the diameter at breast height of tree species in the stand within a certain range.

As shown in **Figure 3**, the mean tree height of tree species increased with the increase of species diversity and species richness, and then decreased, i.e., the mean tree height of tree species in the sample area showed a single-peaked curve relationship with α diversity index and species richness. The R^2 was 0.9867, 0.9261, 0.9770 and 0.646, respectively, which were all good fits. From the fitting calculations, it can be seen that, except for the Shannon-Wiener diversity index, the Simpson diversity index, the Pielou evenness index and the Margalef richness index can reach the maximum value for the average tree height of tree species at 0.8206, 0.9023 and 4.5830, respectively. As a whole, within a certain range, species diversity has a contributing effect on tree height of tree species within the stand, and the Shannon-Wiener diversity index has the highest degree of influence on it.

5. Conclusion and discussion

Species composition and population structure affect the growth of trees to some extent[25]. In this study, through the survey of species composition in natural secondary forest sample plots in different regions, it was found that 48 species belonging to 17 families and 31 genera investigated in all sample plots. Among them, Longgang Mountain contained the largest number of families, genera, and species, followed by Hada Ling, Changbai Mountain, Laozi Ling, Zhang Guangcai Ling, and Xiao Xing'an Ling, and the overall number of species decreased with latitude. The overall number of species decreases with the increasing latitude, which is similar to the results of studies on American forest commu-

nities[26] and subtropical plant communities[27]. Overall, elm, stained maple, and buffalo willow were the dominant species in each region, and studies have shown that the number of dominant species within a stand affects the tree growth within a stand to some extent[28], and the differences in dominant species among regions in this study were small and therefore neglected.

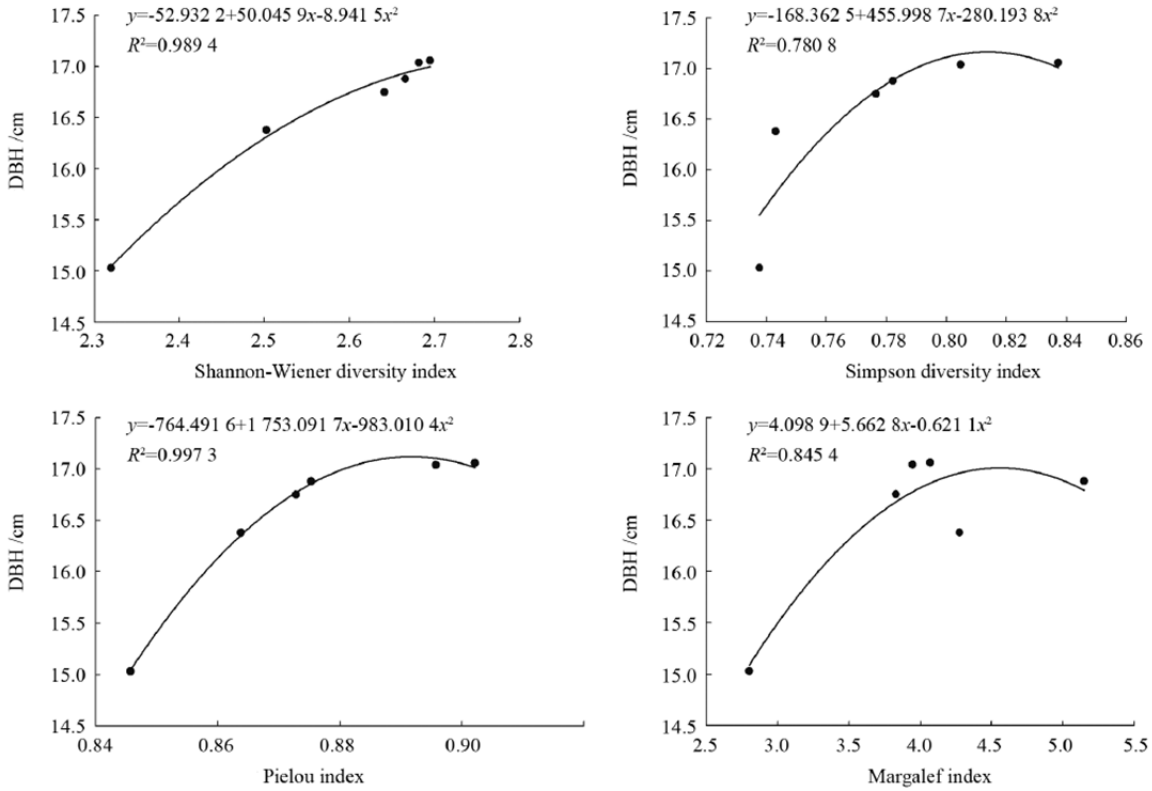

Figure 2. Relationship between biodiversity and DBH in different areas.

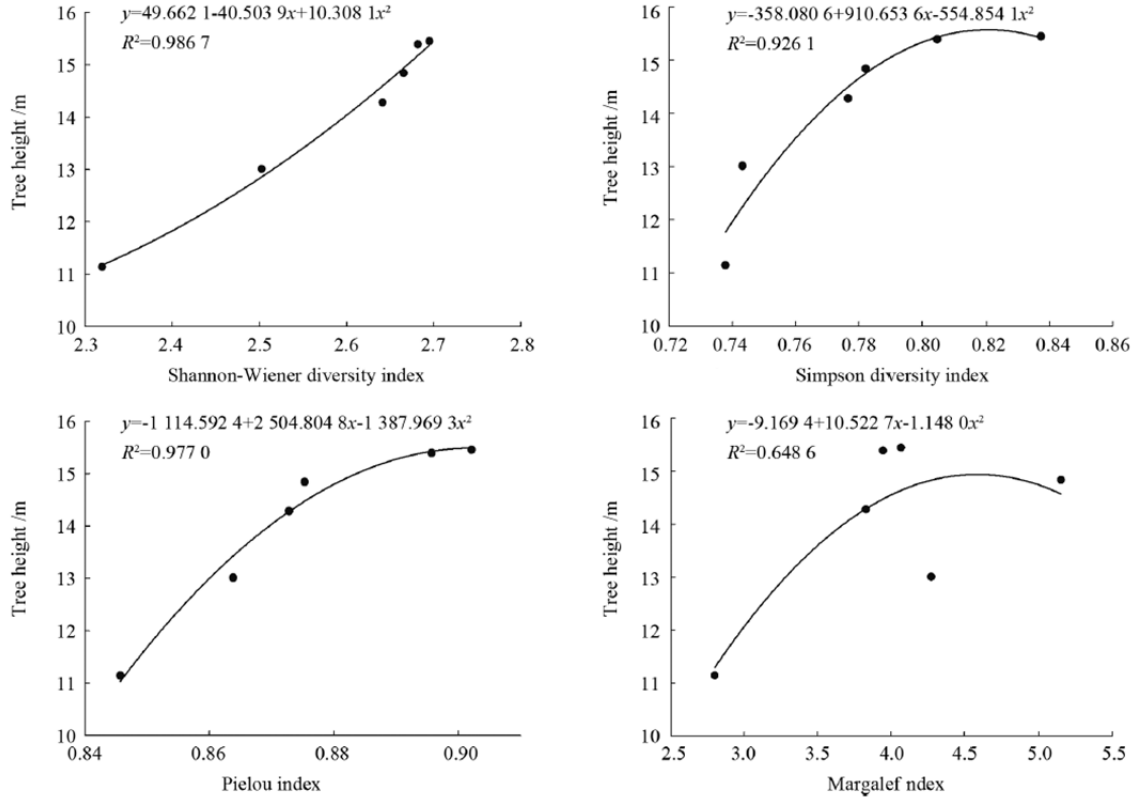

Figure 3. Relationship between biodiversity and tree height in different areas.

In this study, α-diversity index and β-diversity index[21] were used for analysis aiming to understand the community species composition and tree growth between local homogeneous habitats and different habitats in the forest stand. It was found that the species α-diversity in natural secondary forest samples in different regions was the largest in Changbai Mountain and the smallest in Xiaoxinganling. While the richness was the largest in Longgang Mountain and the smallest in Xiaoxinganling. A result indicates that species richness gradually decreases with increasing latitude, and the higher the latitude, the smaller the number of species. The diversity index is influenced by latitude, as well as species composition, community structure, dominant tree species and environmental conditions[25]. The Sφrensen diversity index ranged from 0.1724 to 0.2681. The largest Sφrensen diversity index was found between the Xiaoxinganling and Longgang Mountain areas, and it indicated that the two areas had the fewest species in common, while the smallest Sφrensen diversity index was found between the Laojialing and Zhangguangcai Ridge areas. On the contrary, the Sφrensen diversity index between Laozi Ridge and Zhangguangcai Ridge was the smallest, and the number of species shared between them was the largest. Therefore, it can be found that the greater the difference in latitude between regions, the more obvious the difference in diversity indices between them. In addition, the Cody diversity index increased with decreasing latitudinal gradient, and the lower the latitude, the greater the Cody diversity, and it indicated a higher rate of community succession[29].

By analyzing the diameter at breast height and tree height of tree species in natural secondary forest sample plots in different regions, we found that the average diameter at breast height and average tree height in each region shown CBS > LYL > LGS > ZGCL > HDL > XXL. The largest tree species at diameter at breast height in each region was Mongolian oak in Changbaishan region, and the smallest diameter at breast height was Tyrannus sylvestris in Longgang Mountain. The species with the largest height in each region was Liriodendron spp, the smallest tree height is yellow pineapple in Longgang Mountain area. This indicates that the species grows better in Changbai Mountain area, and the other areas are relatively inferior, and the larger the latitude, the smaller the average diameter at breast height and the average height of trees.

In this study, the relationship between species diversity and mean diameter at breast height and mean height of tree species was found to increase and then decrease with species diversity and species richness in both cases. It is that the mean diameter at breast height and mean height of tree species in the sample area showed a single-peaked curve relationship with α-diversity index and species richness, and the fitting effect was good in both cases. The mean diameter at breast height and the mean height of tree species in the sample site showed a single-peaked curve relationship with the α diversity index and species richness, and the fit was good with large R^2 values. Therefore, it can be seen that within a certain range, species diversity has a certain promotion effect on the diameter at breast height and height of tree species in a stand, but it should not be too high. This is consistent with the results of Zhang *et al*.[30] and Symstad *et al*.[31] regarding the relationship between species diversity and tree diameter at breast height, tree height and biomass. But there are also different findings, for example, Montserrat *et al*.[32] and Thompson *et al*.[33] found a negative relationship between species diversity and tree growth, while Kahmen *et al*.[25] and Grace *et al*.[34] showed no relationship between the two. The main reason for the inconsistent results is that the current studies focus only on the relationship between species diversity and tree growth, thus ignore the possible effects of regional environmental conditions, climatic conditions, species composition, soil fertility, and intra- or interspecific relationships.

In summary, the species survey and analysis of the natural secondary forest sample plots in different regions revealed that all the sample plots contained 48 species belonging to 17 families and 31 genera. Among them, Longgang Mountain contained the largest number of families, genera and species, followed by Hada Ling, Changbai Mountain, Laozi Mountain, Zhangguangcai Mountain and Xiaoxing'an Mountain; the α-diversity index of

species in the sample plots was the largest in Changbai Mountain and the smallest in Xiaoxing'an Mountain. The greater the difference in tude between regions, the more obvious the difference in species β-diversity index and the higher the rate of community succession. The ship between mean diameter at breast height and mean tree height in each region is CBS > LYL > LGS > ZGCL > HDL > XXL; within a certain range, species diversity has a significant effect on the mean diameter at breast height and mean tree height of species in a stand. Within a certain range, species diversity has a positive effect on the mean diameter at breast height and mean height of species within a stand. The present study explored the relationship between species diversity and tree growth in a stand under large-scale conditions based on previous studies, which is representative in terms of geographical space.

Conflict of interest

The authors declare that they have no conflict of interest.

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