中国湖南省におけるコウヨウザン人工林の相対直径の特性分析

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Analysis of Characteristics of the Relative Diameter of Chinese Fir Artificial Stand in Hunan, China

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Abstract: This article deals with a study on the stand diameter structure rules by using the method of relative diameter, based on the Chinese Fir (*Cunninghamia Lanceolata*) artificial stand in Huang Feng Qiao forestry center in Hunan, and gives the characteristics of the relative diameter structure of the Chinese Fir artificial stand through studying the relations between the relative diameter and normal distribution and the *Weibull* distribution.

Key words: chinese fir artificial stand, relative diameter, normal distribution, weibull distribution

Introduction

The state of distribution of all kinds of trees in the stand is called Stand Diameter Structure; and because the stand diameter is easy to measure and is the base of many forestry management technologies, theories of tree measurement, and tables, so stand diameter structure is the basic stand structure measurement. There are many methods to research stand diameter structure, but the method of relative diameter has important biological significance. Relative diameter is the ratio of every tree diameter (di) to the stand average diameter (Dg) (that is: $Ri=di/Dg$). Because in the same density stand, the tree diameter can reflect the competitive ability of the trees in the stand to a certain extent, that is to say, the relative diameter can show the competitive ability of the trees in the stand, so the relative diameter is often used as the tree competition target in the simple tree growth model. So researching the structural characteristics of relative diameter is the basis for understanding the rules of stand structure and is very important for forestry management technology and for working out the digital table of tree measurement.[1,2,3,4] This article concerns the analysis of relative diameter, using the Chinese Fir artificial stand in Huang Feng Qiao forestry center in Hunan and serving for the scientific management of the Chinese Fir artificial stand.

General Situation of the Research Region

Huang Feng Qiao forestry center is in the intermit of Luo Xiao mountain and lies to the southwest of Mount Wu Gong; it lies at longitude 113° 04'～113° 42'east and latitude 27° 06'～27° 14'north. Its altitude is $115m \sim 1270m$. The source rock of the soil is a majority of board-leaf rock, then lime rock, and a little granite and grit-stone; there are country yellow soil, red soil, purple soil and yellow-brown soil. The forestry center has a subtropical seasonally-wind wet climate, an average yearly air temperature of 17.8℃, 292 frost-free days, and an average yearly rainfall of 1411mm. It mostly contains the Chinese Fir and has an area of 10158hm^2, the forest area is 7720.8 hm^2, and the Chinese Fir occupies 5464.1hm2 or 70.77%.

Materials and Methods

1. *Source of the materials.*

The materials originate from the 60 Chinese Fir Artificial Stand samples in Huang Feng Qiao and were obtained by the college students of Central South Forestry University in 1996 and 1997. Using the "X^2test" with a notability level of $\alpha=0.05$ to test the distribution of diameter by tree number,[1] and then prove that the distribution of diameter of the Chinese Fir artificial same age pure stand obeys the rules of normal distribution.

2. *Research methods.*

We tried: To make sure of the changing range of the stand diameter by analyzing the value range of the relative diameter of the stand, to educe the natural diameter span based on relative diameter and cumulate the distribution instance of the percent by analyzing the tree

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Table 1. The relations between stand relative diameter and stand age.

Age class	Sample numbers /block	Lower limit of relative diameter Rmin	Upper limit of relative diameter Rmax	Largest difference of relative diameter
I	5	0.3984	1.7342	1.3358
II	8	0.4226	1.7063	1.2837
III	13	0.4582	1.6835	1.2253
IV	10	0.4742	1.6311	1.1569
V	9	0.4853	1.6226	1.1373
VI	7	0.5015	1.6168	1.1153
VII	5	0.5184	1.6024	1.0840
VIII	3	0.5216	1.5921	1.0705

Table 2. The comparison of stand diameter change of Chinese Fir artificial stand.

Sample number	Stand characteristics					Normal distribution value		Practical value	
	Tree numbers	*Dg*/cm	*Dp*/cm	Age	Status index	*Rmin*	*Rmax*	*Rmin*	*Rmax*
1-1	1617	18.5	18.1	34	10	0.51	1.73	0.58	1.74
1-2	2250	11.4	11.2	15	20	0.40	1.80	0.50	1.85
1-3	1933	9.4	9.0	10	24	0.32	1.83	0.44	1.83
1-4	1750	12.8	12.5	33	10	0.47	1.65	0.48	1.70
1-5	1233	20.7	20.3	35	12	0.49	1.77	0.56	1.80
1-6	2050	14.7	14.4	36	8	0.57	1.74	0.62	1.76
1-7	916	22.2	21.9	34	12	0.52	1.71	0.55	1.77
1-8	1417	17.0	16.5	19	18	0.45	1.76	0.49	1.76
1-9	1217	19.9	19.7	35	14	0.54	1.68	0.63	1.71
1-10	2583	8.6	8.5	9	24	0.37	1.86	0.41	1.88

number, to research the characteristics of the relative diameter by analyzing the relation between relative diameter and the statistic values of the normal distribution characteristics and the relation between relative diameter and the statistical values of the *Weibull* distribution characteristics for diameter.

Results and Analysis

1. *Range-changing of the relative diameter.*

Research was done on the changing range of the diameter by using the relative diameter as a target and the change only alters with alterations in the stand age for the normal managed stand. The 60 Chinese Fir artificial stand samples can be grouped by age class, and cleaned up; then the value range of the relative diameter of every sample can be calculated. The results are shown in Table 1.

It can be found from Table 1 that the value range of the relative diameter of the Chinese Fir artificial stand is [0.4~0.5, 1.6~1.8] and the change range is correlative to the stand age. The change range of the relative diameter of the infant stand is bigger than that of a ripe or overripe stand, that is to say, the change range of the relative diameter decreases as the stand age increases.

2. *Relation between the relative diameter and the statistical values for the diameter normal distribution characteristics*

1) Relative diameter based on normal distribution.

Usually, to describe the diameter structure rule for a same-age pure stand, we use the normal distribution function, so we can figure out the value range of the stand relative diameter based on normal diameter distribution.

There is a relation between the proportion of the average diameter of the stand at chest-height section area (Dg) and the arithmetic average diameter of the stand (Dp), that is:

$$Dg^2=Dp^2+S^2 \qquad (1)$$

In this equation Dg stands for the stand average diameter, Dp stands for the arithmetic average diameter of the stand, and S stands for the standard difference of the stand diameter. And we can use the changing coefficient (C), ($C=S/Dp$) and formula (1) to educe following:

$$Dg^2= Dp^2[1+(S/Dp)^2]$$

$$Dg^2= Dp^2(1+C^2)$$

$$Dg= Dp(1+C^2)^{0.5} \qquad (2)$$

As the stand diameter distribution obeys the normal distribution rules, we can make use of the method of three times standard difference, well that the 99.7% of the total tree number within [$Dp-3S$, $Dp+3S$], as in the following:

Table 3. The distribution of the stand diameter based on *Weibull* distribution.

Sample number	Stand diameter /cm	Stand density number/hm²	*Weibull* distribution parameters			Tree diameter smaller than (b+a)	
			a	b	c	Number	Percent
2-1	9.7	2966	5.0	5.31	2.1047	1864	62.84
2-2	22.4	916	11.0	12.22	2.9648	600	65.50
2-3	18.5	1633	9.0	10.25	2.6548	1033	63.29
2-4	15.9	1100	7.0	9.78	2.4944	667	60.64
2-5	21.5	1583	13.0	9.11	2.0718	983	62.11
2-6	11.4	3500	5.0	6.71	2.1071	2183	62.37
2-7	17.0	1600	9.0	9.04	2.0124	967	60.44
2-8	19.9	1217	11.0	10.10	2.3839	650	60.25
2-9	21.6	1300	13.0	9.54	2.0684	798	61.38
2-10	12.5	2250	7.0	6.23	2.4023	1417	63.97
Average							62.28

$dmin = Dp - 3S = Dp(1-3C)$

$dmax = Dp + 3S = Dp(1+3C)$

With the definition of the relative diameter we can figure out the value range of the relative diameter which, based on the normal distribution, is the following:

$Rmin = dmin \quad Dg = (1-3C) \quad (1-C^2)^{0.5}$ (3)

$Rmax = dmax \quad Dg = (1+3C) \quad (1+C^2)^{0.5}$ (4)

In formula (3) and formula (4) *Rmin* is the lower limit of the relative diameter, *Rmax* is the upper limit of the relative diameter, *dmin* is the least diameter of the stand, *dmax* is the biggest diameter of the stand and *C* is the changing coefficient of the stand diameter.

2) Test of the lower and upper limits of the stand relative diameter

Choosing materials from ten samples at random, we compared the stand diameter distribution based on the normal distribution with the stand diameter distribution that was shown by relative diameter. Conclusions are shown in Table 2.

We can see the error but a quite approach between the biggest and least diameter value that results from the relative diameter and the normal distribution value from Table 2. It shows that it is feasible to analyze the stand diameter structure by using relative diameter.

In order to check the stand relative diameter value range which results from the normal distribution, we can make comparison and supposition about the binate data of the lower and upper limits of the stand relative diameter. Supposing that the practical values of the lower and upper limits of the stand relative diameter are "x_i" and the forecast value based on the normal distribution is "y_i" and the sample number is "m", then we have the following formulas:

$k_i = xi - yi$

$k_0 = (k_1 + k_2 + \cdots + k_m)/m$

$s^2 = [(k_1-k_0)^2 + (k_2-k_0)^2 + \cdots + (k_m-k_0)^2]/m$

$t = k_0(m-1)^{0.5}/s$

After working on the materials of the 60 samples, we made the following, separate conclusions: The "t" value of the stand relative diameter lower limit is -1.8541 and the upper limit is -1.9257. By checking the statistics double digital table of the "t" distribution[2], we could get $t_{0.05}(m-1) \doteqdot 2.0000$, then to all stand relative diameter lower and upper limit exists as $|t| < t_{0.05}(m-1)$. So we can consider that there is no notable difference between the stand relative diameter value range, based on the normal distribution, and the practical value range.

3. *Relation between the relative diameter and the statistical values for the diameter Weibull distribution characteristic*

Because it is convenient and adaptive to use *Weibull* distribution to simulate the stand diameter structure, recently, the *Weibull* distribution is often used in the dynamic forecast model of the stand diameter.

When if using *Weibull* distribution to describe the distribution of the stand diameter, there is a density function of the stand diameter, that is: $f(x) = (c/b)[(x-a)/b]^{c-1}\exp[-(x-a)/b^c]$. By moving the axis to make a = 0, we can get the following *Weibull* distribution density function:

$f(x) = (c/b)(t/b)^{c-1}\exp[-(t/b)^c]$ (5)

Integrating formula (5) gives us the distribution function of the diameter distribution ($F(x)$), and then the following formula when $x = b > 0$:

$F(b) = 1 - e^{-1} \doteqdot 0.63$ (6)

Formula (6) shows the corresponding ratio is 63% when x<b after moving the axis; in fact, it shows that in the stand number of trees whose diameter is smaller than (b+a) accounts for 63% of the stand. After choosing 10 samples at random, using the *Weibull* distribution to test the distribution of tree diameter, making parameter a as the lower limit value of the smallest diameter class in the stand diameter distribution, and using the

Table 4. The percent of cumulative numbers of trees at the relative diameter equal to 1.0.

Sample number	Stand diameter /cm	Tree number /hm^2	Accumulated tree number corresponding to relative diameter 1.0 /number	Accumulated tree number percent /%
3-1	10.0	2266	1400	61.78
3-2	18.3	1217	716	58.83
3-3	8.6	2583	1466	56.78
3-4	12.8	1750	1087	62.15
3-5	16.0	833	527	63.32
3-6	11.4	2250	1283	57.03
3-7	21.6	1300	733	56.41
3-8	22.4	916	600	65.50
3-9	9.7	2966	1583	53.38
3-10	15.9	1100	667	60.61
Average				59.58

approximation-estimation method which was advanced by Bailey to get parameters b and c, we get the results shown in Table 3.

From Table 3 we can see that the theoretical forecast value (63%) of the stand diameter distribution based on the *Weibull* distribution simulation is very close to the practical value (62.28%). On this basis and using the small probability theory, we can do a supposition-test about the total average.[2,5] Supposed in every sample regarding the percentage of trees whose diameter is smaller than (b+a) as "xi" to make statistic supposing and set "H_0": There is no prominent difference between the percentage of trees whose diameter is smaller than (b+a) and "63%". Then there are:

$$x_0=(x_1+x_2+\cdots+x_n)/n$$
$$s^2=[(x_1-x_0)^2+(x_2-x_0)^2+\cdots+(x_n-x_0)^2]/n$$
$$U=(x_0-0.63)(n-1)^{0.5}/s$$

The result, based on the materials of 60 samples, is $U=-1.47$. Because the sample numbers is sixty and it is a big sample, we can check the double-digit table of the normal distribution to get $U_{0.05}=1.96$; then $|U|<U_{0.05}$, so we should accept H_0 and consider the percentage of trees whose diameter is smaller than (b+a) as 63%.

If we use relative diameter to research the number of trees distributed in the stand, we can also use the relative diameter to show the tree diameter and change the tree number in every diameter class for the relative value and count out every diameter class tree number accumulating percent. Choosing ten samples at random and count out the corresponding tree number accumulating percent of every sample when setting the relative diameter as 1.0, we get the position of the stand average diameter (*Dg*) in the tree number accumulating distribution curve and the results are shown in Table 4.

Use the small probability theory to do a supposition-test about the total average once more. Set the accumulating tree number percent corresponding to the 1.0 relative diameter in every sample as "yi", and supposed "H_1": There is no notable difference between the accumulating tree number percent corresponding to the 1.0 relative diameter and 60%. Then we have the following formulas:

$$y_0=(y_1+y_2+\cdots+y_n)/n$$
$$s^2=[(y_1-y_0)^2+(y_2-y_0)^2+\cdots+(y_n-y_0)^2]/n$$
$$U=(y_0-0.60)(n-1)^{0.5}/s$$

The result, based on the materials of 60 samples, is $U=-1.88$. Because the sample number is sixty and it is a big sample, we can check the double-digit table of the normal distribution[2,5] to get $U_{0.05}=1.96$, then $|U|<U_{0.05}$, so we should accept H_1 and consider the tree number percentage corresponding to 1.0 relative diameter as equal to 60%.

From the results of Table 4 and the statistical supposition-test, we can find that the practical count result accords with the conclusion "The percentage of the stand average diameter (*Dg*) in the tree number accumulating distribution curve is approximately 55%~64% and close to 60%"[1,5], and at the same time it is similar to the conclusion that the percentage of trees whose diameter is smaller than (b+a) is 63% based on *Weibull* distribution. It shows that there is a close relation between the stand average diameter (*Dg*) and the *Weibull* distribution parameters a and b, and it can be also seen from the data of Table 3. After the regression simulation, based on the 60 samples, we can get the correlative coefficient r is 0.9953.

Discussion and Conclusions

The minimum and maximum value range of the Chinese Fir artificial stand relative diameter is [0.4~0.5, 1.6~1.8] and the changing range of the relative diameter will decrease as the stand age increases. The stand diameter range distribution based on relative diameter is quite close to the forecast result that is based on three times the standard difference of the general normal distribution. The tree number accumulation percent that corresponds to a relative diameter equal to 1.0 is also similar to the conclusion that the percentage of trees whose diameter is smaller than (b+a) is 63% based on *Weibull* distribution.

There is a close linear correlation between the stand average diameter (*Dg*) and the Weibull distribution parameters a and b and *Dg*≒a+b, that is to say the position of the 1.0 stand relative diameter corresponds to the position of the sum of the *Weibull* distribution parameters a and b.

Relative diameter, normal distribution and *Weibull* distribution can all be used to analyze the rule regarding the stand diameter structure. However relative diameter has shown its superiority in that it can set a different diameter and different tree number stand at the same scale to make analysis and comparison.

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中国湖南省におけるコウヨウザン人工林の相対直径の特性分析

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要　約

本研究は，中国湖南省におけるコウヨウザン人工林について，相対直径と正規分布およびワイブル分布の関係を通じて，林分の直径構成の特性を明らかにしたものである．林分の直径構成は林分構造を知る上での基本であり，相対直径に基づく直径分布の特性分析は植物生態学的にも重要な意義を持つものである．

相対直径とは，林分の平均胸高直径に対する各立木の胸高直径の比率であり，立木相互の競争関係の度合いを示すものである．従って，相対直径の特性を明らかにすることは林分構造の基本的特性を知る上でも，また林分情報の収集や森林経営技術上の観点からも大変重要なことである．

コウヨウザン人工林における相対直径の最少・最大値は0.4～1.8の範囲にあって，林内における変化の範囲は林齢の増加に伴って縮小する傾向にある．その分布範囲は正規分布における予測値に非常に近似している．また，相対直径が1.0に相当する立木の累積本数割合は，ワイブル分布に基づくパラメタ（b+a）より小さい直径の立木比率が63%である推測結果にもほとんど一致している．林分相対直径とワイブル分布のパラメタa；bとの間には一次の相関関係が認められる．

相対直径，正規分布及びワイブル分布は林分の直径構成に関する基準の分析に応用することが可能である．特に相対直径は，直径や本数が異なる林分について同じ基準で分析したり比較したりするのに応用できる点で優れている．