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Differences in the Diameter Distributions of Plantations between Sugi (*Cryptomeria japonica* D. Don) and Hinoki (*Chamaecyparis obtusa* Sieb. et Zucc.)

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Using the Weibull distribution, changes in the diameter distributions in planations of Sugi (*Cryptomeria japonica* D. Don) and Hinoki (*Chamaecyparis obtusa* Sieb. et Zucc.) with age-class were examined. From the results, it was recognized that the spread of the distribution in Sugi plantations becomes larger for higher age-class in comparison with Hinoki plantations. This suggests that in cases where the purpose of forests management is to create a forest with homogeneous diameters, different thinning methods must be adopted for Sugi and Hinoki.

INTRODUCTION

The Weibull distribution is well fitted to the diameter distributions (Kakihara, 1982). Therefore, using the Weibull distribution, the study of diameter distributions in plantations has advanced. As a result, it has been clarified how the diameter distribution changes with age or by thinning (Kakihara and Kinashi, 1984 ; Kakihara, 1985), and the method of thinning on the basis of diameter distribution has been examined (Kakihara, 1987). However, the way in which the diameter distribution differs according to species has not yet been studied. The diameter distribution is a good representation of the stand composition and offers basic information for the study of stand management technology (Kakihara, 1982). Subsequently, clarification of the differences in the diameter distribution among species has led to the establishment of stand management technology appropriate for each species. Therefore, as to Sugi (*Cryptomeria* ***japonica*** D. Don) and Hinoki (*Chamaecyparis obtusa* Sieb. et Zucc.), which are the main species used in silviculture in Japan, the types of differences existing in the diameter distribution between both species were clarified using the Weibull distribution, and the problem of thinning was examined from the results.

MATERIALS AND METHODS

The experimental forest 13 for Sugi and forest 14 for Hinoki set up by Forest and Forest Products Research Institute, and the Kyushu University Forests in various areas of Japan were used in this study. Inasmuch as measurements have been carried out several times for each experimental forest, the number of studied forests is 43 for

Table 1. Stand composition and the Weibull parameters of Sugi experimental forests.

Age-class	Experimental forests	Age (years)	No. of trees per 0.1 ha	Mean diameter (cm)	a	b	c
II	Teradoko	15	172	9.7	1	9.6	4.0
	Kikuchisuigen	16	271	11.1	3	9.1	2.9
	Kaminoyama	18	262	11.6	5	7.4	2.8
	Teradoko	20	172	13.9	3	9.5	4.5
	Shirami	20	260	16.7	5	13.1	3.0
	Mean	18	227	12.5	3	9.7	3.4
III	Kikuchisuigen	21	271	13.6	5	9.7	2.6
	Kaminoyama	24	253	13.5	5	9.5	2.9
	Teradoko	25	164	16.5	5	13.7	4.5
	Kikuchisuigen	30	232	18.1	5	13.8	4.5
	Mizunashihira	30	272	21.1	9	13.6	2.5
	Mean	25	230	16.6	6	12.1	3.4
N	Shintate (D)	32	112	22.8	13	10.5	2.2
	Mizunashihira	35	195	22.8	11	13.2	3.5
	Ichinotaniyama	37	156	21.4	9	14.0	2.1
	Kaminoyama	39	168	16.9	9	8.9	2.5
	Rokumanzan	40	200	18.4	5	15.2	2.3
	Mean	37	166	20.3	9	12.4	2.5
V	Ichinotaniyama	42	87	25.9	9	18.9	3.0
	Tanaka	42	100	27.6	15	14.1	3.1
	Seburizan	43	130	25.1	11	15.8	2.6
	Kaminoyama	45	167	17.5	9	9.6	2.4
	Tanaka	47	73	31.9	19	13.4	2.8
	Mean	44	111	25.4	13	14.4	2.8
VI	Ohata	51	58	34.3	17	19.4	2.6
	Shintate (D)	53	55	31.3	17	16.1	2.3
	Seburizan	54	94	28.4	13	17.3	2.4
	Kikuchifukaba	56	106	30.6	13	19.6	3.0
	Seburizan	59	94	29.9	13	18.7	3.0
	Mean	55	81	30.9	15	18.2	2.7
VII	Kikuchifukaba	61	59	34.9	23	13.3	2.2
	Mizutani	61	60	41.2	25	20.5	2.6
	Shintate (E)	65	70	33.8	13	22.5	2.3
	Mizutani	66	44	44.7	29	17.8	2.3
	Shintate (E)	70	69	35.9	13	25.9	2.2
	Mean	65	60	38.1	21	20.0	2.3

Sugi and 47 for Hinoki. Five forests from every age-class, i. e., a total of 30 studied forests, were chosen from among these forests as arranged from young forests to old forests, covering age-classes II to VII (See Tables 1 and 2). Each measured value was taken before thinning. The number of Sugi trees was less than the number for Hinoki, but the diameter of the former was larger than in the latter. This is due to the fact that the growth of Sugi is better than that of Hinoki, and management aimed at maintaining a lower stand density is carried out for the former.

Tables 1 and 2 can be regarded as experimental results obtained by two-way layout with 2 factors and 5 repetitions. Therefore, analysis of variance was carried out, the main effects and interactions of species and age-class on the Weibull pa-

Table 2. Stand composition and the Weibull parameters of Hinoki experimental forests.

Age-class	Experimental forests	Age (years)	No. of trees per 0.1 ha	Mean diameter (cm)	*a*	*b*	c
II	Onigami	12	288	8.9	1	8.6	4.9
	Onigami	17	288	11.3	1	11.2	5.2
	Onsendake	17	223	15.8	5	9.2	3.7
	Asakawa	18	350	8.7	3	6.8	3.3
	Maruyama (A)	18	234	9.1	3	6.8	3.3
	Mean	16	277	10.8	3	8.5	4.1
III	Onigami	22	208	14.1	7	7.8	4.2
	Asakawa	23	294	11.3	1	11.2	5.3
	Imori	24	218	12.8	5	8.7	3.8
	Ohtaki	27	258	11.8	1	11.8	3.4
	Imori	30	212	14.7	5	10.8	3.4
	Mean	25	238	12.9	4	10.1	4.0
IV	Taminedando	32	259	13.0	3	11.3	2.9
	Imori	34	204	16.2	9	8.1	2.3
	Nasumichi	35	195	17.8	9	9.9	2.9
	Ohtaki	37	188	16.0	3	14.4	3.5
	Yamasesakurei	37	166	17.4	5	13.7	4.0
	Mean	35	202	16.1	6	11.5	3.1
V	Yagura	41	121	20.5	11	10.6	3.9
	Yamasesakurei	41	143	19.3	9	11.5	3.1
	Ohtaki	42	133	18.2	11	8.2	2.7
	Nasumichi	46	131	22.9	11	13.3	3.1
	Arahira	50	103	23.0	13	11.7	2.8
	Mean	44	126	20.8	11	11.1	3.1
VI	Yagura	51	95	24.1	15	10.1	3.1
	Ryozen	55	106	21.6	11	11.8	3.2
	Arahira	55	100	26.1	15	12.4	2.6
	Nasumichi	56	92	27.0	15	13.4	3.3
	Yagura	56	77	26.2	17	10.4	2.7
	Mean	55	94	25.0	15	11.6	3.0
VII	Arahira	61	98	28.3	15	14.8	2.9
	Maruyama (B)	64	173	19.5	9	11.9	2.5
	Ryozen	64	79	25.9	17	10.0	2.5
	Hontano	65	100	30.0	17	14.6	2.5
	Ryozen	68	69	27.6	17	11.9	3.0
	Mean	64	104	26.3	15	12.6	2.6

rameters were clarified and then the difference in the diameter distribution between Sugi and Hinoki was examined from the results of the analysis.

RESULTS

The results of analysis of variance are shown in Table 3. The main effect of age-class was significant at the 1 % level for parameters a, *b* and also c, a and *b* increasing, and c decreasing with age-class in both species (See Tables 1 and 2). For main effect of species, *a, b* and also c were significant at the 1 % level. As shown in

Table 3. Analysis of variance for the Weibull parameters.

Source of variation	D. F.	a M. S.	a F	b M. S.	b F	c M. S.	c F
Age-class (A)	5	323.20	30.90**	69.96	10.14**	1.32	4.78**
Species (S)	1	86.40	8.27**	183.40	26.58**	7.21	26.10**
A×S	5	9.44	0.90	30.08	4.36*	0.53	1.92
Error	48	10.46		6.90		0.28	
Total	59						

D. F., Degree of freedom; M.S. , Mean of square; * Significant at the 1 % level; ** Significant at the 1% level.

Tables 1 and 2, a and *b* were larger in Sugi, and c was larger in Hinoki. In interaction of species and age-class, only *b* was significant at the 5 % level. This indicates that *b* increases with age-class, but that the degree of increase in Sugi is larger than in Hinoki.

Considering the characteristics of the Weibull parameters (Kakihara, 1985), the differences in the diameter distribution between Sugi and Hinoki can be stated as follows.

1) Minimum diameter in Sugi is larger than in Hinoki.

2) The peak of the distribution in Sugi lies on the side of smaller diameter in comparison with Hinoki.

3) The spread of the distribution in Sugi is larger than in Hinoki, and difference in the spread between both species becomes evidently greater with age-class.

In order to gain a better understanding of the above-mentioned results, the diameter distributions of hypothetical stands (age-classes II, IV and VI) were estimated by the following method.

Using the mean values in Tables 1 and 2, the equations for estimation of the number of trees per 0.1 ha, a, *b* and c, were calculated for Sugi and Hinoki, respectively. In addition, as there is no interaction of species and age-class as to *a* and c, the common regression coefficient to both species was calculated initially, and this regression coefficient was used in the calculation of equations for estimation of Sugi and Hinoki, respectively. The results indicate equations (1) to (8).

Sugi

$$a = -2.914 + 3.129A \quad (1) \quad r = 0.99$$
$$b = 5.235 + 2.501A \quad (2) \quad r = 0.98$$
$$c = 3.962 + 0.247A \quad (3) \quad r = -0.98$$
$$\log N = 2.800 - 1.116 \log A \quad (4) \quad r = -0.93$$

Hinoki

$$a = -5.081 + 3.129A \quad (5) \quad r = 0.97$$
$$b = 7.737 + 0.703A \quad (6) \quad r = 0.89$$
$$c = 4.445 - 0.247A \quad (7) \quad r = -0.94$$
$$\log N = 2.774 - 0.927 \log A \quad (8) \quad r = -0.95$$

where *A* stands for age-class and N for the number of trees per 0.1 ha. *r* is the correlation coefficient between the Weibull parameters and age-class or log N and log

Table 4. Number of trees and the Weibull parameters of the hypothetical stands.

Age-class	Number of trees per 0.1 ha	a	b	c
		Species : Sugi		
II	291	3.3	9.3	3.5
IV	134	9.6	13.4	3.0
VI	94	15.9	17.5	2.5
		Species : Hinoki		
II	313	1.2	9.1	4.0
IV	164	7.4	10.6	3.5
VI	113	13.7	12.0	3.0

A.

The number of trees per 0.1 ha and the Weibull parameters of the hypothetical stands obtained using equations (1) to (8) are shown in Table 4.

The cumulative distribution function of the Weibull distribution is shown by equation (9).

$$F(x)=1-\exp[-(x/b)^c] \qquad (9)$$

where $x=(d_i-a)$ and d_i stands for each diameter.

Using the values in Table 4 and equation (9), the number of trees for diameter class in the hypothetical stands were calculated. Figure 1 shows the result, from which the diameter distribution in plantations of Sugi and Hinoki changes with age-class can be understood concretely.

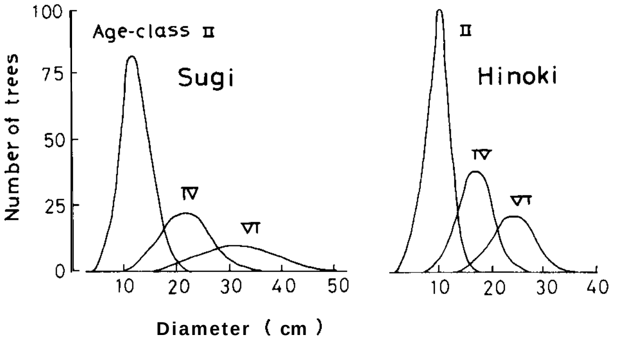

Fig. 1. Changes in the diameter distribution with age-class

DISCUSSION

The existence of the main effect of age-class is a minifestation of results obtained previously (Kakihara, 1985). New findings obtained from the present study are the existences of the main effect of species, and interaction of species and age-class as to parameter b.

As shown in Figure 1, the higher the age-class becomes, the larger the spread of the distribution in Sugi plantations. This indicates that if normal thinning is adopted, a forest with variable diameters will be created. Therefore, if the purpose of forest management is to create a forest with homogeneous diameters, the normal thinning method is not adaptable (Kakihara, 1985). In such a case, it is necessary to devise the new method of thinning using the Weibull distribution (Kakihara, 1987). On the other hand, even if the age-class becomes higher in Hinoki plantations, there is no case in which the spread of the distribution becomes especially larger in Hinoki as in Sugi, as shown in Figure 1. This indicates that even if normal thinning is carried out, a forest with homogeneous diameters will be created. One interesting finding is that if the purpose of forest management is to create a forest with homogeneous diameters, then different thinning methods must be adopted for Sugi and Hinoki.

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