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Analysis of the Diameter Distributions in Mizunara *(Quercus crispula* Blume) Natural Forests Using the Weibull Distribution

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Using the Weibull distribution, changes in the diameter distributions in Mizunara (*Quercus crispula* Blume) natural forests were analyzed. From the results, it was recognized that the Weibull parameters a, *b* and *c* increased with age. The increase of c is considered to be the most noteworthy characteristic of the diameter distributions in Mizunara natural forests. The distribution range of diameters in old Mizunara forests becomes large. Therefore, in cases where the purpose of forest management is to create a forest with homogeneous diameters, it is necessary to devise a new method of thinning.

INTRODUCTION

The Weibull distribution is well fitted to the diameter distributions of plantations and natural forests of even-aged forest type. Accordingly, the correlations between age and the Weibull parameters in plantations have been studied since 1976, and the results have clarified the way in which the diameter distributions of plantations change with age (Kakihara and Kinashi, 1984 ; Kakihara, 1985). However, no such study has been carried out for the diameter distributions of natural forests of even-aged forest type. Therefore, using data from experimental forests set up in Mizunara (*Quercus crispula* Blume) natural forests, which are regarded as even-aged forests, the way in which the diameter distributions in those forests change with age was analyzed. From the results, the problem of thinning was examined.

MATERIALS AND METHODS

Data from 5 experimental Mizunara forests (A, B, C, D and E) established by the Kyushu University Forests in Hokkaido district were used in this study. Mizunara trees occupy almost all areas of the experimental forests, and they are scarcely mixed with other species. Experimental forests A and B were established in 1958, and C, D and E in 1962. Stand factors were measured for each year after establishment, and 1971 and 1979. The outline of stand composition in each year of measurement and the Weibull parameters calculated are shown in Table 1. In those years of establishment, A was a young-aged forest, B, C and D were middle-aged forests and E was an old-aged forest. The precise ages are unknown. Salvage cutting or thinning had not been

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

Experimental forests	Year	$\bar{d}$ (cm)	N/ha	B/ha (m^2)	V/ha (m^3)	*a*	*b*	
A	1958	6.0	3,795	15.0	59.5	1	5.5	1.4
	1971	10.9	1,750	19.4	94.5	3	8.9	1.8
	1979	13.2	1,400	21.9	145.5	3	11.6	2.2
B	1958	13.9	1,192	20.8	149.3	3	12.3	2.3
	1971	17.6	1,083	20.7	175.7	3	16.4	2.5
	1979	19.3	950	30.8	198.1	5	16.1	2.4
C	1962	13.9	1,254	22.2	113.0	3	12.3	2.0
	1971	16.2	1,090	25.3	148.4	3	14.8	2.4
	1979	17.9	910	26.3	164.9	3	16.8	2.3
D	1962	14.3	1,007	18.0	91.3	5	10.4	2.0
	1971	16.5	988	23.5	120.4	5	12.9	2.2
	1979	18.4	762	22.3	134.7	7	12.8	2.0
E	1962	38.2	288	35.1	335.8	17	23.9	2.5
	1971	40.8	281	38.4	358.8	19	24.9	2.7
	1979	41.1	275	38.3	368.3	19	24.8	2.6

$\bar{d}$, Mean diameter; N, Number of trees; B, Basal area; V, Volume

carried out in any of the experimental forests.

The way in which the Weibull parameters of plantations change with age has already been clarified (Kakihara, 1985). Therefore, for comparison with plantations it is necessary to know the correlation between age and the Weibull parameters. However, as the experimental forests used in this study were natural forests, these ages were unknown. Therefore, the method in which the mean diameter is taken instead of age was adopted, and the correlation between mean diameter and the Weibull parameters was examined. From the results, the characteristics of the diameter distributions in Mizunara natural forests was examined.

RESULTS

Using the data in Table 1, the correlation coefficient between mean diameter and the Weibull parameters was calculated. Table 2 shows the results. A possitive correlation was recognized between *a*, *b* or c and mean diameter. This indicates that ***a,*** *b* and also c increase with mean diameter or age.

Table 2. Correlation coefficient between mean diameter and the Weibull parameters.

a	*b*	*c*
0.975**	0.961**	0.735**

** Significant at the 1 % level

Parameter a is the minimum stand diameter ; b is the value of cumulative distribution of diameters at the 63 % point and shows the spread of the distribution ; c expresses the shape of the distribution, and where the value of c is small the distribution has positive skewness (Kakihara, 1985).

Therefore, the above-mentioned result indicates that the diameter distributions of Mizunara natural forests have the following characteristics.

1) In young forests, minimum diameter and also the spread of the distribution are small, and the distribution shape shows a large positive skewness.

2) Minimum diameter and also the spread of the distribution become large with age, and the positive skewnees in the distribution shape gradually becomes small.

As shown in Table 1, parameter c of a very young forest is nearly 1. This indicates that it is an uneven-aged forest (Nishizawa *et al.*, *1976).* In order to ascertain this fact, 25 sample trees were chosen from a young natural forest in this University Forests and the annual ring numbers at 0.3 m above the ground were investigated. As shown in Table 3, the range of annual ringe number was 14 to 23. Thus, Mizunara natural forests which were previously regarded to regenerate nearly simultaneously were actually recognized to be uneven-aged forests. This is considered to be the reason why c reached a value of nearly 1 in young forests.

Table 3. Tree numbers for annual ring number.

Annual ring number	14	15	19	20	21	22	23	Total
Tree numbers	1	1	3	3	4	10	3	25

Next, the reason why parameter c increased with age was examined for experimental forest A. As shown in Table 4, dead standing trees in each year of measurement were of small diameter. Consequently, the variation coefficient of diameters decreased as 0.62, 0.43 and 0.37, and c increased as 1.4, 1.8 and 2.2. Therefore, the reason why c increased with age is that trees of small diameter died successively.

Table 4. Diameter distribution in each year of measurement,

Year		Diameter (cm)												Total	CV_d
		2	4	6	8	10	12	14	16	18	20	22	24		
1958	L	39	32	30	19	13	10	5	2		1			151	0.62
1971	D	34	27	16	2		1	1						81	
	L		6	11	10	12	8	5	5	5	2			70	0.43
1979	D		3	5	4	2								14	
	L		1	5	6	9	9	6	7	4	4	4	1	56	0.37

L, Live standing trees; D, Dead standing trees; CV_d, Variation coefficient of diameters.

In order to gain a better understanding of the above-mentioned results, assuming hypothetical stands with mean diameters of 10, 20, 30 and 40 cm, the diameter distributions of these hypothetical stands were estimated by the following method.

Using the data in Table 1, the following equations for estimation were calculated.

$$a = 4.441 + 0.555\,\bar{d} \quad (1)$$
$$b = 4.989 + 0.005\,\bar{d} \quad (2)$$
$$c = 1.769 + 0.222\,\bar{d} \quad (3)$$
$$\log N = 4.668 + 1.374 \log \bar{d} \quad (4)$$

where $\bar{d}$ stands for mean diameter and N for the number of trees per ha. The correlation coefficient between log N and log $\bar{d}$ was -0.991 and significant at the 1 % level.

The number of trees per ha and the Weibull parameters of the hypothetical stands obtained using equations (1) to (4) are shown in Table 5.

Table 5. Number of trees per ha and the Weibull parameters of hypothetical stands.

Mean diameter (cm)	Number of trees per ha	a	*b*	*c*
10	1,967	1.1	10.0(10.1)	2.0
20	759	6.7	15.0(15.0)	2.2
30	435	12.2	20.0(20.1)	2.4
40	293	17.8	25.0(25.0)	2.7

Parameter *b* can be obtained from Γ_1 corresponding to c and mean diameter by the following equation; $b = (d_i - a)/\Gamma_1$, where d_i stands for mean diameter (Nishizawa, 1978). The values given in parentheses are those of *b* obtained using the above equation. Roth values of *b* are nearly equal.

The cumulative distribution function of the Weibull distribution is shown by equation (5).

$$F(x) = 1 - \exp[-(x/b)^c] \quad (5)$$

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

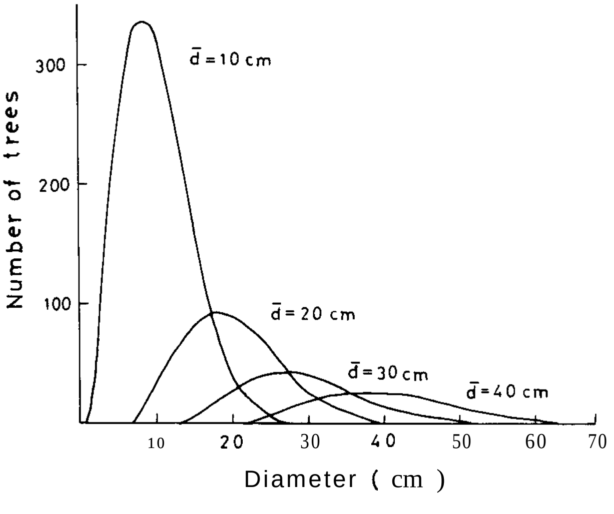

Fig. 1. Changes in the diameter distribution with mean diameter ($\bar{d}$)

Using the values in Table 5 and equation (5), the numbers of trees for each diameter class in the hypothetical stands were calculated. Figure 1 shows the results, from which the diameter distribution changes with age in Mizunara natural forests can be understood concretely.

DISCUSSION

In the case of plantations, the Weibull parameters a and *b* increase, but c decreases with age reversely (Kakihara, 1985). As mentioned above, values of a, *b* and c for Mizunara natural forests increase with age. Therefore, the fact that c increases with age can be stated to be the most distinguishing characteristic of the diameter distribution in Mizunara natural forests.

As shown in Figure 1, as Mizunara natural forests become old, the spread of the distribution becomes large. This indicates that if the purpose of forest management in Mizunara natural forests is to create a forest with parameter c (homogeneous diameters) high in value, the normal thinning method is not adaptable. In such a case, a new method of thinning in which the Weibull parameter c can be increased must be devised. As far as has been clarified, the Weibill distribution is effective for solving this problem (Kakihara, 1987). In addition, the establishment of thinning technology for Mizunara natural forests becomes a serious problem. I would therefore like to stress the importance of the Weibull distribution in studies on new method of thinning for Mizunara natural forests.

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