Growth Prediction in Natural Forest Stands in Sub-alpine Regions

By Satoshi SUGAHARA
Seminary of Forest Management, Fac. Agric., Shinshu Univ.

Introduction

The expression of the frequency distribution of diameters breast high and the prediction of growth in natural stands of uneven-aged timber have been a interesting but difficult problem in forest mensuration. The normal distribution curve and the yield table in even-aged forest stands have not been adaptable to uneven-aged timber because of too wide variation in the ages of individual trees. Besides the diameter breast high of stems in uneven-aged timber does not always monotonously increase in relation to the age of trees for various reasons.

The structure of uneven-aged forest stand is very characteristic. A forest is a community of individuals which has a life of its own. The component parts of a forest bear the same relation to each other as do the individuals in a town. The trees are mutually dependent and at the same time competitive. They protect each other against windthrow and snow break, and the close canopy allows the formation of humus; yet they compete for food, moisture and light. So sharp is this competition that a stand of 1,000 trees per hectare at 100 years may be the final survivors of 10,000 or more seedlings which started on that hectare, the balance having perished in the struggle for existence. The average forest, if left absolutely undisturbed by natural agencies, including fire, insects and wind, and if secure from lumbering operations, would in the course of a century or more develop into what is called a climax or ulitimate type of forest which is suited to the particular region in which it grows. In natural forest would be found trees of many ages and many different species, and, for the most part, reproduction would be started beneath holes in the canopy made by the death of veterans. Therefore, undisturbed natural stand appears to be composed of an assembly of groups of trees each more or less even-aged. These groups often contain a few scattered individuals, which are considerably bigger and taller than the rest. These are remnants of a former stand. Beneath the main body of the stand, in the case of larger timber, may be an understory of newcomers, which are considerably smaller than the rest. Combining the main body, remnants and newcomers, the frequency curve of diameters in natural stands may be shown in the L-shaped form.

The normal frequency curve that has been adapted for younger even-aged stands, therefore, has not been adaptable to natural timber. Under these circumstance, it seems that the exponential frequency curve proposed by H. A. Meyer is relatively suitable to the distribution of diameters in natural stands.

The prediction of growth in uneven-aged timber is a more difficult problem. In the case of even-aged stands, the cycle based on the age of the stand is of the highest importance. In uneven-aged stands, any harvesting must inevitably be by means of some sort of partial cutting. The essential growth problems of such stands, therefore, are concerned with their growth after a partial cutting. If the larger trees in a stand are removed, a net growth will at once begin, for two reasons. The trees removed are, in general, those that were growing slowest and in which the volume mortality was highest. The effect of removing the deteriorating trees is obvious. But in addition to this, their removal will admit more light to the remaining trees and so accelerate their growth. Because of acceleration, the actual growth after cutting will be materially greater. The effect of acceleration may be expressed as an increase in periodic diameter growth. This increase is the dependent variable, while the severity of cutting may be the principal independent variable. Therefore, in the temporary investigation, there is no way but approximate approach. The growth prediction methods in use for some time have been based upon the measurement of past diameter growth as revealed by annual rings and the assumption that this growth will be continued at the same rate in the future. These methods are suited only to short-term predictions, and have the further disadvantage that they require an independent estimate of mortality, which is inevitably subject to considerable error.

The transition of distribution of diameters breast high in a stand may be now considered as a key for the prediction of growth in natural fir stands, which have not been reached the climax after cutting or disturbing by natural agencies.

One purpose of this treatise is to determine whether or not diameters in natural fir forest stands distribute in compliance with H. A. Meyer's curve. Other problem dealt with in this paper is to try the prediction of growth in natural stands of uneven-aged timber by means of the distribution table.

A few reports have hitherto been published on this problem. However, those reports have been concerned with qualitative observations and quantative analyses have not yet been performed.

This work owes to Prof. H. Watanabe at Gifu Univ., under whose direction this study has been carried out. To Mr. Y. Oouchi at Gifu Univ., Mr. S. Tatsumi at Kagawa Univ. and Mr. M. Kajihara at Kyoto Pref. Univ., the author has been greatly indebted for gathering the necessary materials at Kurumijima forest. And the author is particularly indebted to Mr. Y. TAKAHASHI and all the students of the seminary of forest management at Shinshu Univ. for their assistance in this investigation. To all of them, his most grateful acknowledgement must be paid. This investigation has been aided by the grant of scientific research from the Education Ministry, to which the author offers his many thanks.

I The Field Sample

This study has been carried out as a part of "Studies on the secondary natural forest stands grown in sub-alpine regions", so the basic data of this treatise have been gathered with other materials at a part of the state forest of Kurumijima, under control of Kuguno Forestry Station, in August and September 1964.

The forest lies on the foothills of Mt. Ontake, to the east of Gifu Pref.. The climate may be described as cool temperate, although winters are very hard and protracted. Because the region, on the whole, enjoys the benefit of the summer monsoon, which gives it a fair rain-supply. In the greater part of the forest land, hyroxene andesite bed rocks are thickly covered with lava, and thinly with braun forest soil or wet podzol soil. The forest, in which sample plots have been taken, lies between 1, 700 m and 2, 100 m in altitude. The resinous forests naturally

Table 1. Sample Plot Figures

Plot number	Plot area (ha)	Number of stems in every diameter class														
		4	10	16	22	28	34	40	46	52	58	64	70	76	82	Total
1	0.04	31	41	32	14	10	—	—	—	—	—	—	—	—	—	128
2	〃	13	32	15	7	6	2	—	1	1	—	—	1	—	—	78
3	〃	16	15	8	5	3	2	5	3	2	—	—	—	—	—	59
4	〃	13	13	5	9	1	3	—	—	3	1	1	1	—	1	51
5	〃	6	11	9	12	4	2	2	—	—	1	1	1	1	—	50
6	〃	15	10	8	6	1	6	2	—	1	1	—	—	—	—	50
7	〃	33	17	9	1	6	3	3	—	1	—	—	—	—	—	73
8	〃	19	20	10	11	5	1	1	—	—	—	—	—	—	—	67
9	〃	9	16	12	10	5	2	—	1	—	—	—	1	—	—	56
10	〃	38	33	9	11	10	1	—	3	1	—	—	—	—	—	106
11	〃	16	40	24	13	9	3	2	2	—	—	—	—	—	—	109
12	0.01	24	18	10	5	1	—	—	—	—	—	—	—	—	—	58
13	0.02	9	44	20	9	5	—	—	—	—	—	—	—	—	—	87
14	〃	4	14	4	3	2	1	1	—	—	—	—	—	—	—	29
15	0.01	9	18	9	3	2	—	—	—	—	—	—	—	—	—	41
16	〃	15	9	5	5	1	—	—	—	—	—	—	—	—	—	35
17	〃	25	12	5	—	—	—	—	—	—	—	—	—	—	—	42
18	0.005	26	10	3	1	—	—	—	—	—	—	—	—	—	—	40

predominate, but they are also of a mixed type, including Shirabe (*Abies Veitchii Lindl.*) and Ooshirabe (*Abies Mariesii Mast.*) and occasionally Toohi (*Picea jezoensis Carr. var. hondoensis Rehd.*) and Kometsuga (*Tsuga diversifolia Masters*), with Dakekanba (*Betula Ermani Cham.*), and giving the usual aspect of northern temperate mountains, owing to the cold, damp, foggy atmosphere.

Square or rectangular sample plots of 0.005～0.04–hectare sampling units were taken throughout these natural fir stands in Kurumijima, and located mechanically in areas of timber which had not been reached mature forest after cutting or disturbing by natural agencies. The natural fir forest type was represented by 18 sample plots.

On each plot a tally was made of all trees, whose diameters breast high were 1 cm or larger, by species. Judgment of the average age of the forest stand was based upon borings for age. Not less than three age–sample trees were taken on each plot, and their species, diameter breast high and age were recorded. Then other measurements for the secondary natural fir stands were carried out. Necessary sample plot figures are tabulated in Table 1.

II Analysis of the Data

In the laboratory the tally on each tally sheet was converted to a per hectare basis. The number of stems in each stand per hectare represented by the entire tally of sound trees were grouped together in 6–cm interval of diameter class, in order to obtain a smooth curve of the frequency distribution of diameters breast high, and unsound trees were excluded from consideration.

The relation between height and diameter breast high in these natural fir stands has been presented in Figure 1, and the desirable volume table for these timber was preferred. On each sheet were also computed the basal area per hectare, the stand volume per hectare, the average diameter breast high of stems and the average age, as indicated by the age–sample trees. These figures were tabulated in Table 2.

§ 1 Testing goodness of fit of H. A. Meyer's formula for the distribution of the diameter breast high in natural fir stands which have not been reached mature forest after cutting or disturbing by natural agencies

The formula proposed by H. A. Meyer is represented as follows:

$$y=k\cdot e^{-\alpha x} \qquad (1)$$

where y is number of stems per hectare in x–th diameter class,

x is diameter breast high of stems in cm

k and α are constants.

By logarithmic transforming, formula (1) may be written

$$\log y = \log k - \alpha \cdot x \cdot \log e \tag{2}$$

and the relation between $\log y$ and x can be expressed by line. The constants of the formulae for such lines were computed by means of the method of least squares, and tabulated in Table 2 or Table 3.

The variate in the formula proposed by H. A. MEYER is one that theoretically can take any value whatever in a given range $a \leq x \leq b$, which may be finite or infinite. The diameter breast high in a stand can be considered such a continuous variate and perhaps may be taken continuously in a given range in case of the measurement for a great many stems. But in the actual frequency

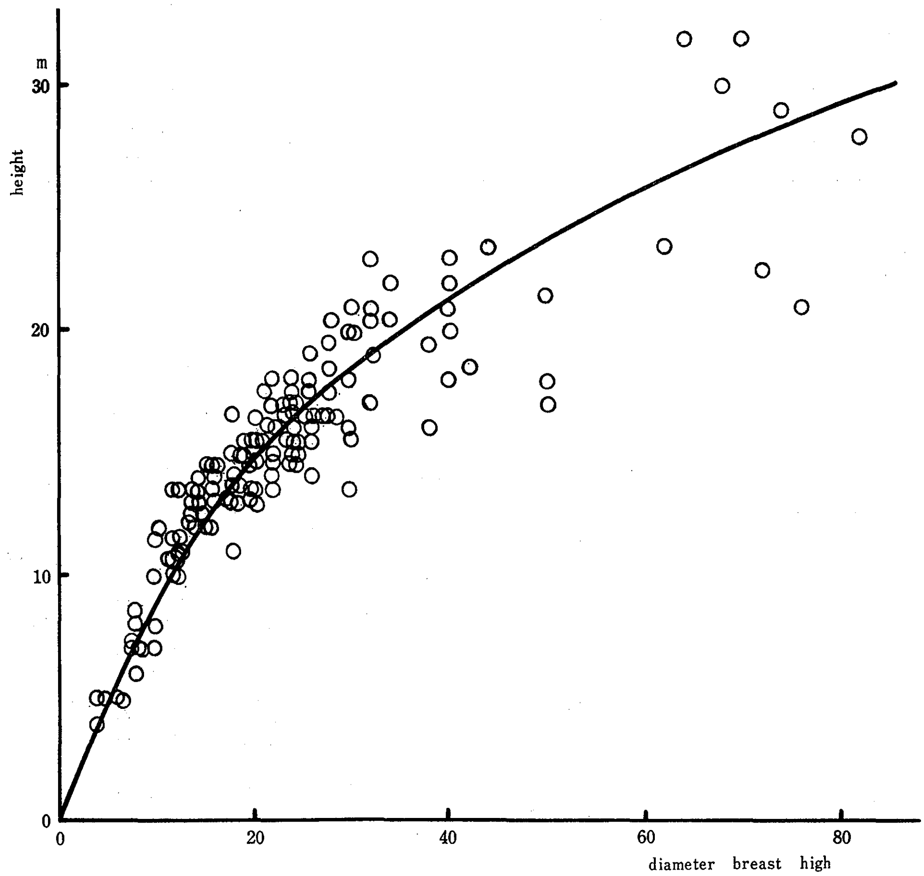

Figure 1. The Relation between Height and Diameter Breast High

Table 2. Test of Goodness of Fit to H. A. MEYER's Formula
—— Values in case that all stems are taken ——

Plot number	Average d.b.h. (cm)	Maximum d.b.h. (cm)	Average age (years)	per hectare		Constant		Values of χ^2	
				Basal area (m^2)	Volume (m^3)	k	α	(1)	(2)
1	12.8	30	55	54	372	228	0.056	46.82	31.35
2	15 0	72	82	54	469	106	0.056	140.76	130.01
3	17.7	52	70	60	560	66	0.042	24.80*	22.71*
4	20.0	82	103	75	807	46	0.034	72.55	67.25
5	21.4	74	112	71	716	50	0.037	70.54	63.01
6	16.8	56	74	46	414	65	0.051	33.58	32.03
7	12.5	50	117	41	347	101	0.063	79.54	35.60
8	13.3	40	65	33	248	183	0.097	44.37	26.68
9	16.6	68	72	45	394	73	0.047	55.62	46.81
10	12.9	50	86	58	482	198	0.074	66.57	65.72
11	15.2	48	85	68	537	206	0.072	120.72	70.42
12	9.9	26	57	62	398	940	0.127	84.73	36.49
13	13.0	30	56	70	469	224	0.046	464.47	397.64
14	14.3	40	69	33	251	88	0.060	117.27	98.80
15	11.8	28	51	57	374	368	0.080	186.70	135.16
16	10.5	26	55	44	297	420	0.100	35.98	32.52
17	7.1	14	32	23	118	729	0.134	0.72**	—
18	6.9	22	—	42	229	1901	0.183	5.14**	—

Note : Values of χ^2 (1); Values in case that all stems are taken.
Values of χ^2 (2); Values in case that stems less than 7 cm in d. b. h. are neglected.
**; accepted at the 1 % level of significance.
*; accepted at the 0.1 % level of significance.

Table 3. Test of Goodness of Fit to H. A. MEYER's Formula
—— Values in case that stems less than 7 cm in d. b. h. are neglected ——

Plot number	Original				Corrected			
	Constant		Values of χ^2		Constant		Values of χ^2	
	k	α	(1)	(2)	k	α	(1)	(2)
1	428	0.084	6.58**	—	—	—	—	—
2	132	0.061	84.51	31.09	168	0.076	51.96	13.31**
3	59	0.038	26.25	13.30**	—	—	—	—
4	40	0.032	75.87	53.87	48	0.039	12.48**	—
5	62	0.041	48.67	48.20	79	0.055	22.54	22.27
6	60	0.049	33.69	33.01	80	0.056	3.77**	—
7	68	0.052	52.80	29.72	105	0.063	12.83**	—
8	292	0.108	21.98	19.37	328	0.113	24.63	17.24
9	93	0.053	42.18	39.78	148	0.080	15.92**	—
10	188	0.073	70.12	45.97	280	0.086	12.77**	—
11	409	0.092	4.63**	—	—	—	—	—
12	1771	0.156	30.37	16.50	1054	0.121	3.11**	—
13	1195	0.122	1.29**	—	—	—	—	—
14	182	0.085	24.56	5.48**	—	—	—	—
15	1063	0.128	5.43**	—	—	—	—	—
16	521	0.110	35.21	32.03	713	0.122	46.35	27.33
17	—	—	—	—	—	—	—	—
18	2231	0.192	0.24**	—	—	—	—	—

Note : Values of χ^2 (1); Values in case that stems less than 7cm in d. b. h. are neglected.
Values of χ^2 (2); Values in case that stems less than 13cm in d. b. h. are neglected.
**; accepted at the 1 % level of significance.

distributions for the sample plots, diameters breast high take only certain values and are correctly referred to as discontinuous. For example, there is not a stem in 40 cm-, 58 cm- and 64 cm-diameter breast high class in the second sample plot. If we want to apply H. A. MEYER's formula for the distribution of diameters breast high in a stand, it is necessary to take the values of all the class-marks in a given range so as to obtain to continuous one in appearance. So, in case of necessity, two or more diameter classes had been combined, and the actual variates were converted to continuous ones.

And then the constants of the formula were computed by means of the method of least squares, and tabulated as corrected in Table 3.

The hypotheses, that diameters breast high of stems in natural fir stands distribute in compliance with H. A. MEYER's curve, were rejected in 16 plots at the 1 % level of significance by means of the statistics chi-squares in case that all stems are taken (Table 2). Leaving out the stems, whose diameters breast high were less than 7 cm, the rejections of that hypotheses were done in 10 plots (Table 3). Being corrected for the continuous distribution in appearance, the hypotheses were rejected only in 3 plots (Table 3).

§ 2 Inducing the relationships among various factors for the distribution of diameters breast high in a stand

1 The constant α or k and number of stems per hectare (N)

The variation of α or k was sensibly dependent on that in N. The constant α or $\log k$ increases uniformly with the amount increased of $\log N$. Equations expressed by the line of least squares are presented as follows:

$$\alpha = -0.35215 + 0.13049 \log N \qquad (3)$$

$$\log k = -4.27085 + 1.96341 \log N \qquad (4)$$

2 The constant α or k and average diameter breast high in a stand (d_a)

The constant α or $\log k$ decreases uniformly with the amount increased of d_a.

$$\alpha = 0.20714 - 0.00836\, d_a \qquad (5)$$

$$\log k = 4.07201 - 0.11859\, d_a \qquad (6)$$

3 The constant α or k and maximum diameter breast high in a stand (d_m)

The constant α or $\log k$ decreases uniformly with the amount increased of d_m.

$$\alpha = 0.16539 - 0.00162\, d_m \qquad (7)$$

$$\log k = 3.43586 - 0.02167\, d_m \qquad (8)$$

4 The constant α and k

The constant k increases with the value of α. The equation, which has been derived by the method of least squares, are

$$\log k = 1.33637 + 12.05070\alpha \qquad (9)$$

And we can lead the following equation from (3) and (4):

$$\log k = 1.02775 + 15.04644\alpha \qquad (10)$$

and from (5) and (6):

$$\log k = 1.13397 + 14.18541\alpha \qquad (11)$$

and from (7) and (8):

$$\log k = 1.22351 + 13.37654\alpha \qquad (12)$$

Within 0.03∼0.18 of α, these lines given from equation (10), (11) or (12) lie in the confidence belt of line of least squares at the 5 % level of significance. Therefore, we can regard the equations (10), (11) or (12) as the substitute of the equation (9).

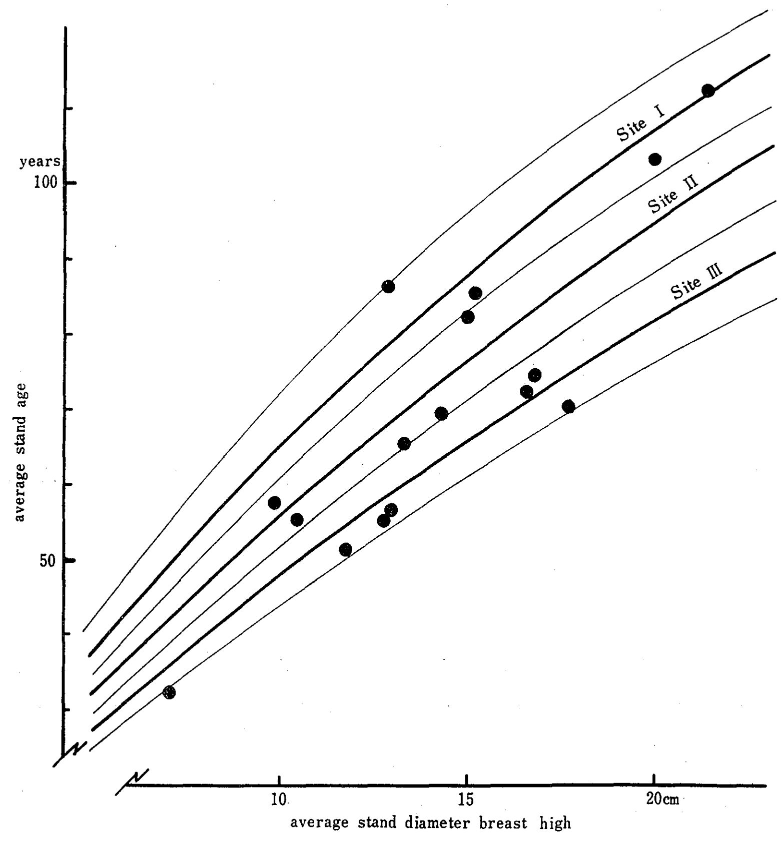

Figure 2. Site Index Curve for Natural Fir Stands

§ 3 Presuming the average stand age in relation to the average diameter breast high in a stand

The tally sheets, on which the average diameter breast high and the average stand age had been recorded, were sorted into 5-cm average diameter classes, and the average age of each class determined. These ages were plotted over their corresponding average diameters, and a smooth curve was drawn through the points (Figure 2). The resulting values, the average ages of natural fir stands in relation to average diameters breast high, are as follows:

Average diameter (cm)	Average age (years)
5	32
10	54
15	76
20	95

Such average ages are relative; and they express, not the number of years a given stand has been in existence, but the periods of time which that stand has taken to develop from smaller-sized material and the number of years it will require to develop into larger sizes. Also, these relative ages are regionwide average, and are not applicable to any specific stands.

III Statistical Consideration

As a result of the above-mentioned, we can be led to the following conclusions.

(1) In a dense forest, especially in a dense and slender forest, we have a larger value of k or α, and we find a smaller value of these in a sparse forest.

(2) In a forest, whose average diameter breast high or maximum diameter breast high is a bigger one, we have a smaller value of k or α, and we find a larger value of these in a slender forest.

(3) The value of k or α variates more sensibly with N than d_a, but its difference is not significant.

(4) The constant k increases with α in these natural fir stands, this tendency has been already found by H. A. Meyer in natural beech timber, and by S. Miyoshi in natural oak forests.

(5) We may say that the frequency distribution of diameters breast high in natural fir stands after cutting or disturbing by natural agencies can be induced from the number of stems per hectare, or the average diameter breast high of stems, or the maximum diameter breast high of stems in the stand.

(6) Although the age of each stem is not always independent on the diameter breast high of the stem, the average stand age is dependent on the average stand

diameter breast high. But the variation is too widely, so the relation had better represent with the sheaf of curves.

IV Distribution Table

The key to estimate the distribution of diameters breast high in natural fir stands which have not been reached mature forest after cutting or disturbing by natural agencies lies in the number of stems per hectare, the average stand diameter breast high or the maximum stand diameter breast high.

The constants of H. A. MEYER's formula were computed from the number of stems, the average stand diameter breast high or the maximum stand diameter breast high with the equations (3), (4), (5), (6), (7) and (8) by the materials, which had been used in this work. In Table 4, these constants are compared with the original constants. From results in Table 4, it can be inferred that it had better prefer the number of stems per hectare or the average stand diameter breast high to the maximum stand diameter breast high as variable. And the dependent variables are tabulated in Table 5.

Being given the constants of H. A. MEYER's formula, the distribution of diameters

Table 4. Comparing with Values of H. A. MEYER's Constants

Plot	Original		From number of stems		From average diameter		From maximum diameter	
number	α	k	α	k	α	k	α	k
1	0.084	428	0.105	409	0.100	358	0.117	610
2	0.076	168	0.077	154	0.081	196	0.049	75
3	0.038	59	0.061	89	0.059	94	0.081	204
4	0.039	48	0.053	67	0.040	50	0.033	46
5	—	—	—	—	—	—	—	—
6	0.056	80	0.052	65	0.066	120	0.075	167
7	0.063	105	0.073	136	0.103	389	0.084	225
8	—	—	—	—	—	—	—	—
9	0.080	148	0.058	81	0.068	127	0.055	92
10	0.086	280	0.094	282	0.099	349	0.084	225
11	0.092	409	0.106	415	0.080	186	0.088	249
12	0.121	1,054	0.139	1,313	0.124	791	0.123	746
13	0.122	1,195	0.122	746	0.098	339	0.117	610
14	0.085	182	0.060	86	0.085	238	0.101	371
15	0.128	1,063	0.119	665	0.108	471	0.120	674
16	—	—	—	—	—	—	—	—
17	0.134	729	0.121	697	0.148	1,698	0.143	1,357
18	0,192	2,231	0.157	2,469	0.149	1,794	0.130	910

Table 5. Basic Values for Distribution Table

(1) based on specified number of stems per hectare

Number of stems	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
Constant α	0.079	0.102	0.118	0.131	0.141	0.150	0.157	0.164
Constant k	162	360	633	981	1,404	1,900	2,469	3,111
Average diameter (cm)	14.9	12.7	11.2	10.0	9.0	8.1	7.4	6.8
Maximum diameter (cm)	51.7	40.5	32.6	26.5	21.5	17.3	13.6	10.4

(2) based on specified average stand diameter breast high

Average diameter (cm)	6	8	10	12	14	16	18	20
Constant α	0.166	0.146	0.127	0.108	0.088	0.069	0.049	0.030
Constant k	2,293	1,328	769	446	258	149	87	50
Maximum diameter (cm)	16.2	21.2	26.2	35.2	47.7	60.1	72.6	85.1
Number of stems	10,415	7,179	4,962	3,425	2,364	1,632	1,126	778

(3) based on specified maximum stand diameter breast high

Maximum diameter (cm)	20	30	40	50	60	70	80	90
Constant α	0.133	0.117	0.101	0.084	0.068	0.052	0.036	0.020
Constant k	1,006	611	371	225	137	83	50	31
Average diameter (cm)	7.5	11.2	12.8	14.4	16.0	17.6	19.2	20.8
Number of stems	6,331	4,400	3,058	2,126	1,477	1,027	714	496

breast high is easily estimated. Namely the number of stems in every diameter class can be estimated from H. A. MEYER's formula.

V Growth Prediction Table

By using the values of this distribution table, the inference of the distribution of diameters breast high in natural fir stands can be easily put into practice. But if this is used only for this purpose, this table is not always necessary. In this section, therefore, still more application of this distribution table may be considered. That is to try the preparation of the simple growth prediction table for natural fir stands, which have not been reached mature forest after cutting or disturbing by natural agencies.

For that purpose, it must be cleared up the following matters;

a) the distribution table,
b) the average stand ages in relation to average diameters breast high,
c) the volumes in relation to diameters breast high,
d) the site.

In these, the matters of a) and b) have been already made clear, and regional volume table has been already available. The site remains to be considered. The site must be considered, as it must be made applicable to individual stands whose sites may differ from the regionwide average.

The key to this problem seems to lie with the ages of plots within the various average diameter classes. The average ages of plots in the 15-cm diameter class was found to be 76 years, but the deviation of individual plot ages from this average was considerable. Expressed as the coefficient of variation, it amounted to 22.5 percent of the average. These differences of the average ages in the same average diameter breast high may be due to a factor which causes some stands to reach a given size much sooner than others, and this factor is cumulative and constant with the passage of time. Whether this is a single factor or several factors working together, or whether it is termed "site quality" or something else, is not important. For the sake of simplicity it will be so termed here, and defined thus: Site quality is an expression of those natural elements in the habitat which combine to control the rate of increase in the average diameter of a timber stand. According to this definition, if the average site will produce an 15-cm stand in 76 years, then sites producing 15-cm stands in, for example, 66 years should be called good; those requiring 88 years to achieve the same result should be called poor. Furthermore, the range between 66 and 88 may be divided into a series of site classes, from the good to the poor, and a similar series may be established for each of the average diameter classes. This has been done in Figure 2, which expresses site quality in terms of average stand diameter and average stand age for the natural fir stand type. Site II, or the average, was represented by the original curve of age over diameter. The other site curves were harmonized with the average according to the same method. It is, of course, obvious that the definition of site quality expressed in Figure 2 is applicable only to stands of natural fir stands, which have been reached mature forest after disturbing by either cultural or destructive agencies in Kurumijima forest.

It is now a simple matter to construct basal area growth curves and volume growth curves for site. The average stand diameters breast high are read from the specified average stand ages by Figure 2. And then the constants of H. A. MEYER's formula are computed from the average stand diameters breast high, the basal areas and the volumes in the stands per hectare for the corresponding average stand diameters are computed by means of distribution table. A set of basal area and of volume curves is obtained for each of the three sites, and these curves converted to table form (Table 6 and Table 7).

The method of site determination and growth prediction for uneven-aged timber stands can now be put into practice, using Figure 2 and Table 6 or Table 7. But these figure and tables are applicable only to natural fir stands, which have

Table 6. Growth Prediction Table
—— Average stand diameter breast high, number of stems per hectare, total basal area per hectare and total volume per hectare in relation to average stand age and site ——

Average stand age	Site index I				Site index II				Site index III			
	Average diameter	per hectare			Average diameter	per hectare			Average diameter	per hectare		
		Number of stems	Basal area	Volume		Number of stems	Basal area	Volume		Number of stems	Basal area	Volume
40	8. 2cm	5, 900	41m²	46m³	6. 7cm	7, 600	42m²	43m³	5. 6cm	9, 100	42m²	41m³
50	10. 7	3, 800	41	52	8. 9	5, 200	41	47	7. 4	6, 800	42	44
60	13. 3	2, 500	43	64	11. 2	3, 500	41	54	9. 1	5, 000	41	48
70	16. 2	1, 600	50	87	13. 5	2, 400	43	66	11. 0	3, 600	41	54
80	19. 3	1, 150	66	139	16. 0	1, 650	49	85	13. 2	2, 500	42	64
90					18. 6	1, 200	61	120	15. 4	1, 800	47	80
100									18. 0	1, 300	58	109

Table 7. Growth Prediction Table
—— Number of stems per hectare, total basal area per hectare, total volume per hectare and average stand age in relation to average stand diameter breast high ——

Average diameter	per hectare			Average stand age		
	Number of stems	Basal area	Volume	Site I	Site II	Site III
6 cm	8, 700	43m²	42m³	31years	36years	42years
8	6, 150	42	45	39	46	53
10	4, 300	41	50	47	55	64
12	3, 050	41	58	55	64	75
14	2, 200	44	69	62	72	84
16	1, 650	49	85	69	80	92
18	1, 300	58	109	76	88	100
20	1, 100	72	177	82	95	107

been reached mature forest after cutting or disturbing by natural agencies at Kurumijima state forest, Gifu Pref..

Summary

1. A method is presented for determining distribution of diameters breast high and predicting growth in natural uneven-aged timber stands, which have not been reached mature forest after cutting or disturbing by natural agencies.

2. The basic data of this treatise have been gathered at a part of the state forest of Kurumijima, Gifu Pref., in summer 1964.

3. The hypotheses, that diameters breast high of stems in natural fir stands distribute in compliance with H. A. MEYER's curve, were accepted in almost sample plots. The formula proposed by H. A. MEYER is represented as follows:

$$y=k\cdot e^{-\alpha x}$$

where y is number of stems per hectare in x-th diameter class,

x is diameter breast high of stems in cm,

k and α are constants.

4. By using H. A. MEYER's formula, the distribution of diameters breast high in natural fir stands, which have not been reached mature forest after cutting or disturbing by natural agencies, was easily represented.

5. The constants k and α are estimated from average stand diameter breast high or number of stems per hectare.

6. By using distribution table, the growth table was prepared in a form such as yield table. Then site was induced as a function of average stand age and average stand diameter.

7. This growth table can be applied for the prediction of growth to any natural fir stand, which has been reached mature forest after cutting or disturbing by natural agencies, in Kurumijima state forest, Gifu Pref..

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Die Zuwachsvermutung in den Tannenurwaldbestände aus den Hochgebirge

Satoshi SUGAHARA
Seminar der Forsteinrichtung, Fakultät der Ackerbauwissenschaft,
Universität zu Shinshu

Zusammenfassung

1. Die vorliegende Arbeit bezweckt, Einblick in einige Problem der Stammzahlverteilung und der Zuwachsvermutung in den Tannenurwaldbestände nach mathematisch-statistischen Grundsätzen zu geben. Eine umfassende Behandlung dieser Frage ist in diesem Rahmen nicht möglich.

2. Bei Untersuchungen über den Hochgebirgebestände in Kurumijima Wald, in der Nähe von Ontake gelegen, im Sommer 1964, wurden die Materialien, die in 18 Probeflächen aus den Tannenurwaldbestände gekluppiert wurden, gesammelt.

3. Die Hypothese, daß die Stammzahlverteilung in den Tannenurwaldbestände analytisch durch die von H. A. MEYER hingewiesene Exponentialfunktion beschreiben werden konnte, wurden aufgestellt. Die H. A. MEYER'sche Funktion werden beschrieben wie folgt :

$$y=k\cdot e^{-\alpha x}$$

Es bedeuten dabei :

y ist die Stammzahl pro Hektar in x-ster Durchmesserstufe,
x ist die Brusthöhendurchmesserswert in Zentimeter,
k und α sind die zahlenmäßige Konstanten.

4. Die obige Hypothese kann in der Mehrheit der Probeflächen für die 1 % Überschreitungswahrscheinlichkeit mit Hilfe eines Chi-Square-Testes erhalten bleiben. Also kann man wirklich urteilen, daß die Stammzahl in den Tannenbestände nach H. A. MEYER'scher Formel annähernd verteilt ist.

5. Die Konstante k bzw. α nimmt gewähnlich mit der Stammzahl pro Hektar (N) zu, aber nimmt mit zunehmendem Mittelduchmesser (d_a), bzw. Maximumdurchmesser (d_m) ab. Der Maximumdurchmesser ist umso größer, je größer der Mitteldurchmesser ist, dagegen je kleiner die Stammzahl pro Hektar ist. Die Konstante k wird größer mit zunehmender α. Die Gleichungsparameter der Kurven wurden nach der Methode der kleinsten Quadrate hergeleitet.

6. Mit Hilfe der oben erwähnten Gleichungen, wurden die Stammzahlverteilungstarife erstellt. Er ist beruht auf der Stammzahl pro Hektar, dem Mittel-

Jour. Fac. Agric., Shinshu Univ. Vol. 4 No. 3 Dec. 1967.

durchmesser bzw. dem Maximumdurchmesser.

7. In der Kenntnis des Mitteldurchmesser kann der Wachstumsgang eines Tannenbestándes leicht angenommen werden. Die Zuwachsvermutungstafel für die Tannenurwaldbestände wurden erstellt mit Hilfe der Stammzahlverteilungstarife. Die Schwierigkeit der Bonitierung wurde störend empfunden. Werden bei der Konstruktion der Zuwachsvermutungstafel sämtliche aufgefundenen Mittelbrusthöhendurchmesserswerte über den Alter aufgetragen, dann ergibt sich ein ziemlich breiter Streurahmen. Dieser Streurahmen wird in 3 Streifen aufgeteilt. Die Mittellinien dieser Streifen geben dann die Durchmesserswerte der einzelnen Bonitäten (I～III).

8. Aber sind die Tafel die in sich geschlossene Lokaltafel, deren Grundlagen örtlich hergeleitet wurden. Sie können daher nicht auf anderen Bereich angewandt werden.

亜高山帯天然生林分の生長量推定

菅　原　　聰
信州大学農学部　森林経理学研究室

要　　約

1. 亜高山帯林分が伐採や災害などによつて開放された後に成立する2次的天然生林分の構造ならびに生長についての検討を試みたものである。

2. 基礎資料は1964年8月および9月に岐阜県胡桃島国有林内の2次的天然生林分内で標本点18点を選んで集めた。これらの2次的天然生林分は，シラベ・オオシラベを主体とし，トウヒ・コメツガならびにダケカンバをまじえたものである。

3. このような異齢の天然生林分の水平的構造は，いわゆる H. A. MEYER によるいわゆる択伐林型として，すなわち

$$y=k\cdot e^{-\alpha x}$$

y : xー直径階に属する林木本数
x : 胸高直径（cm）
k および α : 常数

にしたがう分布型として把握してよいことが確かめられた。

4. H. A. MEYER の式の常数 k および α は，ヘクタール当り林木本数，林分平均直径または林分最大直径の函数としてあたえられることも確かめられた。

5. 地位については問題がいろいろ残つたが，年齢と平均林分直径の函数としてⅠ～Ⅲの3階級に区分してみた。ここでいう地位の概念はきわめて広義的であり，あたえられた条件下においての生長速度の遅速をあらわすものであると考えてよい。

6. 以上の地位ならびに本数分配表を手がかりとして胡桃島国有林内の2次的天然生シラベ林分についての簡易生長量予測表を作成してみた。

7. この簡易生長量予測表は，いわゆる地方表であり，この地方以外での適用が不可能であることは当然である。

8. この簡易生長量予測表を用いての生長量ならびに収穫予測方法は，通常の収穫表による方法と同じである。ただこの場合地位の判定に林分平均直径を用いていることに注意しなければならない。