Evaluation of Forest Growth by Quantification of Environmental Factors

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Since the estimation method of forest growth by the quantification of environmental factors was reported in 1965 (Nishizawa, Mashimo, and Kawabata 1965), more than one hundred schemes of the quantification have been done in Japan for major planting tree species of various regions. Most of these schemes were successful and the results have been used in the actual forest management practice.

For getting good results of the quantification, it is indispensable to choose the effective indicators for estimating the forest height growth in each region where the quantification is carried out. According to the many research works in the past, we know that the indicators such as soil, topography, and geological features may be effective. One can compare quantitatively the effectiveness of selected indicating factors by the quantification.

Quantification of environmental factors

Many sample stands are chosen in a certain region where the quantification is practised and growth of trees and environmental factors are investigated. Sample stands should be planted ones of age of more than 30 years and have not been suffered from any significant damage. It is also necessary that the sample stands are selected from various lands of different topography, geology, and soil in the region. According to the result of our study, more than 200 samples are required for the quantification for one tree species.

The growth of sample stand is denoted by site index which is, in general, the tree height in meter at the stand age of forty years. In order to obtain the site index, site index curves for each region are required. In this study, the site index curves were constructed using stem analysis data of sample trees. For the purpose of practical management, the site index curves are made by yield tables which are ready to use for major tree species.

Eight to twelve items such as soil or topography are chosen and used as the environmental factors. Each item is divided into several categories and the scores are given to these categories basically by the following two equations:

$$\hat{Y} = X_1 + X_2 + \cdots\cdots + X_n \qquad (1)$$

$$\sum_{i=1}^{m} (Y_i - \hat{Y}_i)^2 = \text{minimum} \qquad (2)$$

where $\hat{Y}$ is the estimated site index, Y is the actual site index, $X_1 \ldots\ldots X_n$ are the scores of categories of n items, and m is the number of samples. As the result of calculation, accuracy of the estimation can be evaluated by multiple correlation coefficient between actual and estimated site index. When the coefficient is less than 0.8, the scheme of the quantification is considered to be unsuccessful. The effectiveness of environmental factors as indicators is also evaluated by the calculation of range of scores and partial correlation coefficient between site index and factors.

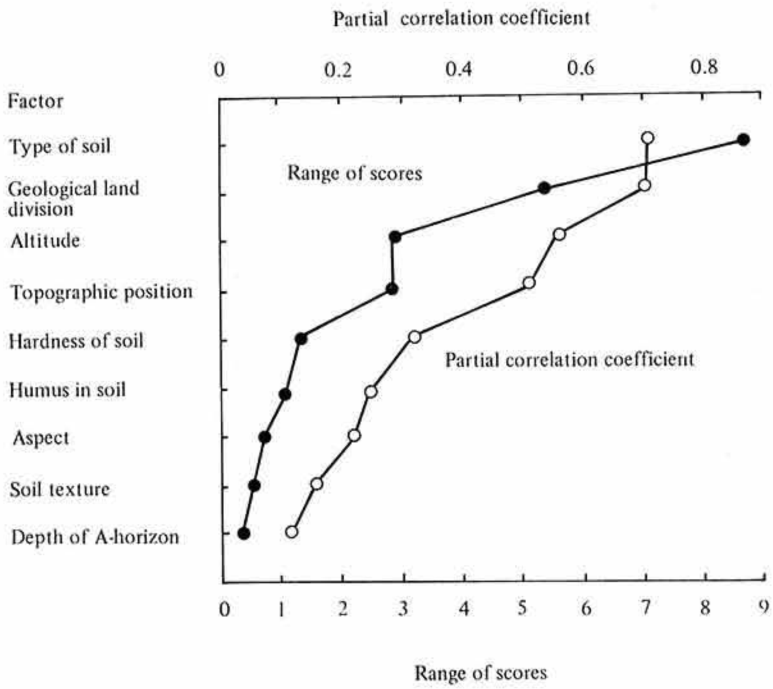

Fig. 1. Partial Correlation Coefficient between the factors and site index, and range of scores in each factor

An example of evaluation of effectiveness of environmental factors

The effectiveness of environmental factors for growth of Sugi (*Cryptomeria japonica*) stand in the Pacific side of central Japan is shown in Fig. 1. The growth of Sugi plantation in this region was measured and data of 190 sample stands were gathered. Following 9 items were chosen as environmental factors:

X_1: geological land division, X_2: altitude, X_3: topographic position, X_4: aspect, X_5: type of soil, X_6: depth of A horizon, X_7: humus content in soil, X_8: soil texture and stoniness, X_9: hardness of soil.

Nine items of environmental factors were divided into 57 categories and scores were given by a computer. The detail of the results was reported by Mashimo (1974) to the Congress of International Society of Soil Science.

This quantification gave very high multiple correlation coefficient ($\rho Y \cdot \hat{Y}=0.963$) and the growth of Sugi plantation in this region can be estimated or predicted precisely by the scores of this quantification.

Soil type is the most effective environmental factor for the growth of Sugi in this region (Fig. 1). The second important factor is geological land division, the third is altitude, and the fourth is topographical position. Five other factors are not so important for the growth of Sugi.

The soils in this region are mostly typical subgroup of Brown Forest Soil group. The soils of this subgroup cover more than half of the forest land in Japan and have high productivity and suitable for tree plantation. The subgroup of Brown Forest Soil are subdivided into six soil types, in the forest soil classification system in Japan (Forest Soil Division 1976), according to the morphological

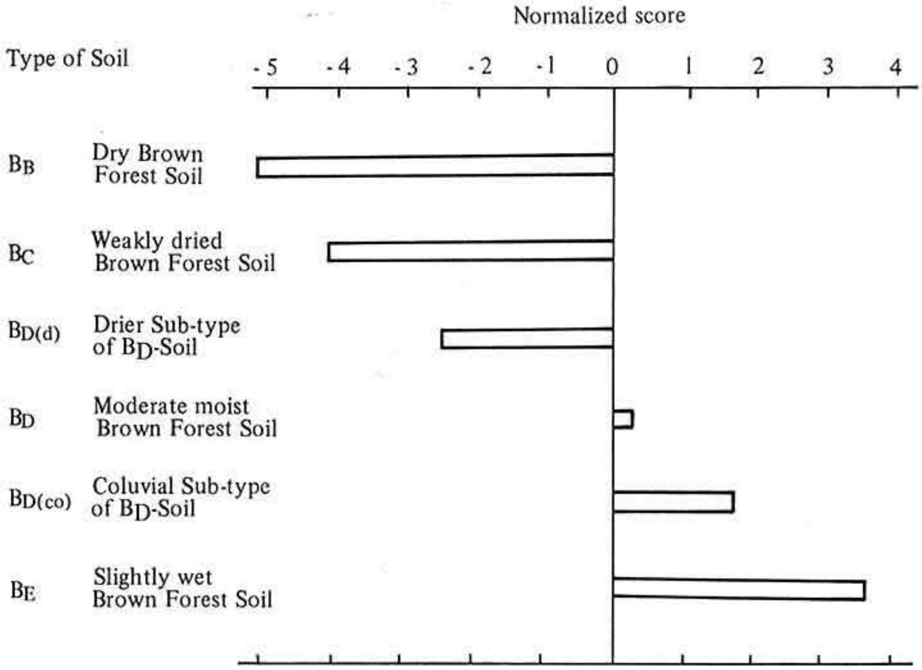

Fig. 2. Normalized scores of "Type of Soil"

features of soil profile such as form of Ao horizon or size and shape of soil structure. The normalized score of soil types shown in Fig. 2 indicates that the soil type is a quite effective indicator for the estimation of height growth of Sugi stands. Site index gets higher in the order of B_B-soil $<B_C$-soil $<B_D$(d)-soil $<B_D$ soil $<B_E$-soil. This evidence is the general trends of the quantification for other tree species or different region.

The surveyed region of this report is divided into 8 unit areas based on the geological features (Fig. 3). Chichibu and Tenryu are well known forestry area. Especially, the palaeozoic sedimentary rock and mature stage mountain zone in the former and the metamorphic rock mountain zone of the latter have high productivity. On the contrary, Amagi vaolcanic mountain zone has poor productivity, particularly soils derived from rhyolite have poor productivity. In general, geological land classification is strongly related to macro topographical and micro climatic land classification and may be effective for the productivity. Altitude is divided into 4 categories shown in Fig. 4 and the scores of the categories are compared. As a matter of course, lower altitude zone has higher productivity

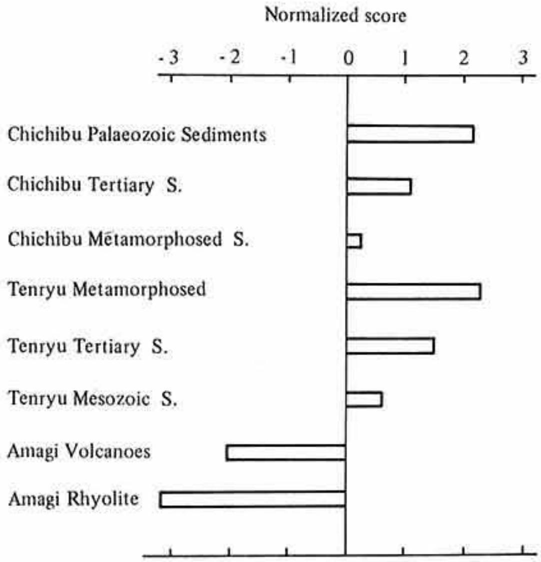

Fig. 3. Geological land division

than higher altitude zone. The upper limit altitude for Sugi plantation in the region is approximately 1,100 m. The warmth index calculated by altitude is also widely used as an effective indicator. Fig. 5 shows the comparison of growth of Sugi in different topographical position and also, as a common knowledge, the growth is better on mountain toe slope or concave slope and poor on top or ridge. The scores in Fig. 6 indicate soft soil is slightly better than hard soil for tree growth.

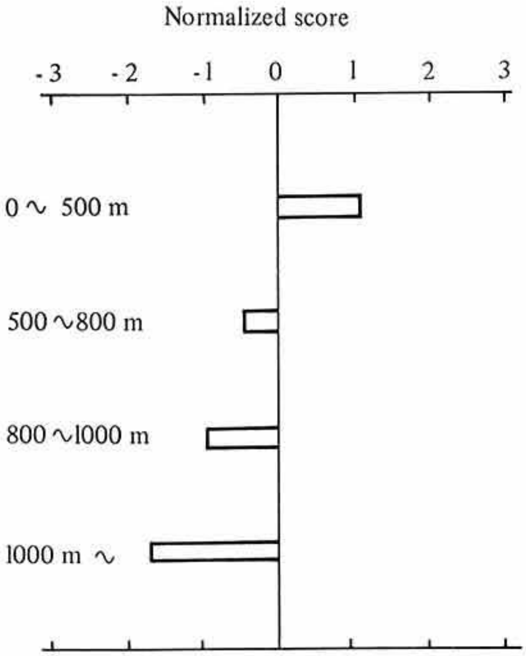

Fig. 4. Altitude

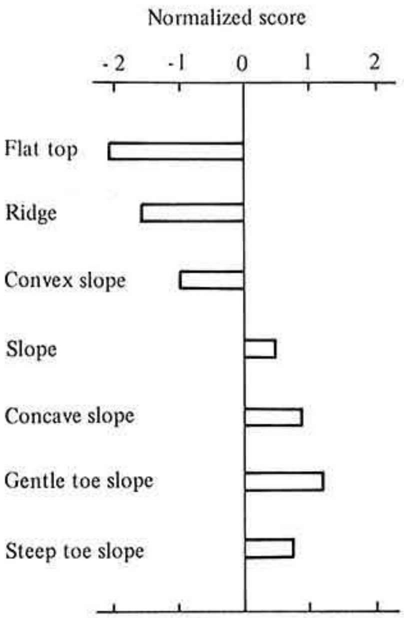

Fig. 5. Topographic position

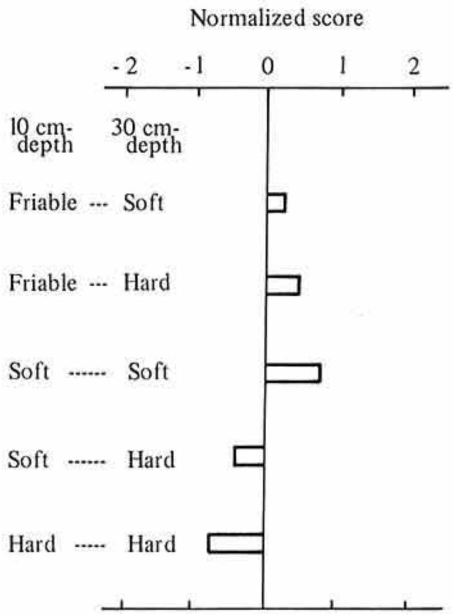

Fig. 6. Hardness of soil

Estimation of effectiveness of environmental factors on growth of major tree species in various regions

The quantification of 46 regions for Sugi, 26 for Hinoki (*Chamaecyparis obtusa*), 13 for Akamatsu (*Pinus densiflora*), 13 for Karamatsu (*Larix leptolepis*), and 1 for Todomatsu (*Abies myriana*) and Buna (*Fagus crenata*) have been successfully accomplished in Japan. The quantification for national forest has been done for selected management planning areas, while administrative unit such as prefecture is the unit area of the quantification for

Table 1. Effectiveness of the factors to the growth of Sugi (*Cryptomeria japonica*)

	Effectiveness order								
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Type of soil	35	3	3	4	1				
Geology	4	14	7	4	5	5	1		2
Altitude	5	7	3	5	6	7	3	3	3
Topographical position		5	13	9	5	7	2	1	4
Inclination	2	1	6	7	3	4	7	7	4
Aspect		1	5	3	8	7	8	7	5
Soil texture, stoniness			1	1	4	5	3	5	19

Table 2. Effectiveness of the factors to the growth of Hinoki (*Chamaecyparis obtusa*)

	Effectiveness order								
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Type of soil	11	12	2	1					
Altitude	6	7	5	3	1		1	1	1
Geology	6	2	6	1	2	1	4	1	1
Topographical position	1	2	3	6	4	7	0	2	1
Aspect			2	3	7	8	0	3	3
Incination			1	4	1	1	8	1	7
Soil texture. stoniness			1		1	2	4	6	10

private forest. The average acreage of the unit area of the quantification is about 1,000 km^2 for national forest and 3,500 km^2 for private forest.

As the growth of Sugi and Karamatsu responds sensitively to environmental factors, the accuracy of estimation of site index is comparatively higher and multiple correlation coefficient exceeds 0.9 for the two species in many regions.

The effectiveness of the factors are estimated by the same way as shown in Fig. 1 and the factors are given the order of effectiveness in every region. The orders of effectiveness of 72 cases of quantification are summed up in Table 1 and Table 2. The most effective factor as the indicator for growth of Sugi is the soil type. Among 46 regions, where the quantification was accomplished, the soil type is ranked at the first order in 35 regions while the soil type is also ranked at higher order in other regions. The second significant factor is geology or geological land classification and the factor is ranked at the second position in many regions. The third is altitude or warmth index and the fourth is topographical position. Although another 5 to 8 items of environmental factors are used for the quantification, they are not so significant for tree growth except for topographical inclination.

In case of growth of Hinoki, the soil type is also the most significant as an indicator and ranked the first or the second order in almost all regions. The second significant indicator is altitude, the third is geology, and the fourth is topographical position. These four factors are also significant for other tree species.

The soil survey of forest land in Japan has been carried out for nearly 30 years and now 1: 20,000 scale soil maps cover 90% of national forest and 1:50,000 scale soil maps cover more than 50% of private forest. In the future, estimation of forest land productivity in Japan will be done more precisely using these soil maps together with topographical maps, geological maps, and aerophotographs.

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