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Classifying Natural Broadleaved Stands by Aerial Photographs and Multivariate Analysis

— The Case of the Applied Forests of Palm Form Working System —

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The palm form working system has been applying to a part of Kyushu University Forest in Hokkaido. It is necessary to classify the natural broadleaved stands corresponding to the planning of timber cut and forest road network to maximize the efficiency of the system. This paper analyzes the classification of forest types based on aerial photographs and multivariate analysis. Data used in this analysis are 4 attributes obtained by photo-interpretation. For the methods of multivariate analysis, the procedures are as follows : 1) The grouping of unit blocks is shown by the dendrogram resulting from a cluster analysis. 2) The unit block is presented by the scatter diagram produced by using principal component analysis. 3) After the mutual relationships between the unit blocks were discussed, each unit block was classified into 8 forest types. The results showed the effective measure for planning of timber cut and forest road network.

INTRODUCTION

The forest type classification of natural broadleaved forests in the applied forests of the palm form working system plays an important role to plan the timber cut and forest road network (Cha *et al.*, 1987). When further adding, the distribution of large and middle-sized trees comes up as an important problem in planning of the timber cut of broadleaved forests by group-selection cutting system.

The palm form working system to maintain a difficult equilibrium between timber production and the securing of the service function of forests was devised in 1961 (Yano and Imada, 1966), and it has been applying to a part of Kyushu University Forest in Hokkaido having an approximate area of 1,170 hectares (from twenty-first to thirtieth compartment). The two silvicultural systems of clear and group-selection cutting system are well combined in the applied forests of the system. Namely, a lower section of hillside is mainly composed of coniferous plantations of KARAMATSU (*Larix leptolepis* G.). An upper section is mainly composed of natural broadleaved stands that MIZUNARA (*Quercus mongolica* var. *grosseserrata* RHED. et WILS) is a dominant and co-dominant tree. Furthermore, the coniferous stands are harvested by clear cutting system with rotation of fifty years, and then the broadleaved stands are simultaneously harvested by group-selection cutting system with final cutting of 150 years and cutting cycle of 50 years (Yano and Imada, 1966).

The information on coniferous stands (for example, the number of trees per hectare, diameter class, height class and so on) are easily obtained from age, site index,

yield table and so on, whereas the collection of data related to broadleaved stands is very difficult.

Accordingly, the broadleaved stand structure of each unit block is estimated by photo-interpretation. Based on the measured values, the forest types are classified by multivariate analysis. (Nishikawa, 1975 ; Pfister and Arno, 1980 ; Tanaka *et al.*, 1987).

INTERPRETATION OF AERIAL PHOTOGRAPHS IN CLASSIFYING FORESTS

The forest features, which can be interpreted on aerial photographs, are either quantitative or qualitative. The qualitative features or photographic images are subjectively identified by the interpreter. Classification keys or guides correlate the various grades of the qualitative features descriptively with the corresponding information. Quantitative features are information, which can be measured such as the height or the crown diameter of trees. The most important information which can be obtained from aerial photographs for forest inventory are the sizes of area categories, such as forest types, cutting classes, age classes, species classes and so on.

In classifying forests, the forest component factors which can be interpreted on aerial photographs are species, height classes, crown diameter, crown density and so on. Among these factors, crown diameter, species and height which can easily be obtained from photo-interpretation are divided into three classes, respectively (Itakaki, 1974). In the photo-plot sampling, the precision of estimation decreases as the number of interpretation variables that goes with the errors of photo-interpretation is larger or the width of each interpretation variables class smaller (Kobayashi, 1970 ; Stellingwerf and Chau, 1981).

In the natural broadleaved stands, it is of common knowledge that there are close relationships between the crown diameters measured by ground survey and those interpreted on aerial photographs, and between the diameter at breast height (D. B. H.) and the crown diameter either measured by ground survey or obtained from photo-interpretation (Onuki, 1986). Accordingly, from what is mentioned above, the choice of interpretation variables is the most important matter in classifying the forest type by using aerial photographs. As considering all possible conditions relating to the above mentioned point of view, the diameter classes at breast height (D. B. H.) are estimated from the visible crown diameters of trees which can easily be obtained from photo-interpretation. The used aerial photographs of which the average flying height above sea level is 1,800 meters and the average scale of an aerial photographs is 1 : 5,000 were taken in 1977. In the 1 : 5,000 scale photographs the crowns of the individual trees of the photo-plots were measured using a dot or circle gauge with circles at a scale of 1 : 10,000. Irregular crowns, such as of large emergent broadleaved trees are best measured two or three times from different angles. The crown diameter is then calculated as the arithmetic mean of these measurements.

The field data measured from the ground sample plots was obtained in 1978 (Chainarong *et al.*, 1979). The independent variables were measured in ground sample plots located in exactly corresponding in photo-plots with the line sampling method, and were obtained by measuring all dominant and co-dominant trees of each plot on the ground. The regression equation estimated by relationship between the field and photo data from the sample plots is as follows :

$$d = -8.972 + 5.2983 \text{ CDp} \quad (r = .831)$$

where d is stem diameter at breast height (D. B. H.) (cm)

CDp is crown diameter obtained by photo-interpretation (m)

In the Kyushu University Forest in Hokkaido, traditional diameter classes consist of middle-sized trees from 22 cm to less than 32 cm and large trees greater than or equal to 34 cm. Accordingly, in corresponding to this equation, the number of large and middle-sized trees per hectare for each unit block were interpreted on the aerial photographs, and then calculated the corresponding coefficient of variations, respectively.

In photo-plots sampling, the photo-plots are systematically distributed and established two plots per hectare with circular 0.10 hectares plot at a scale of 1 : 7000 on each unit block. Table 1 shows the measured values obtained from photo-interpretation, that is to say, the number of trees of each diameter class and the corresponding coefficient of variations of each unit block.

Table 1. Basic stand data matrix obtained from photo-interpretation (Number of trees per hectare and coefficient of variation (CV) (%) of broadleaved forests).

No. of unit block	No. of trees		CV (%)		No. of unit block	No. of trees		CV (%)	
	L	M	L	M		L	M	L	M
2	86.0	27.0	27.0	37.9	24	16.0	83.0	75.6	28.4
3	95.1	32.7	23.0	39.3	25	18.7	98.0	43.3	14.3
4	108.2	38.0	15.3	36.7	26	26.4	99.2	91.1	35.0
5	66.5	32.4	28.2	20.7	27	27.4	74.1	78.9	48.1
6	58.3	40.4	39.7	42.6	28	11.7	80.7	95.0	18.6
7	74.7	36.2	23.1	25.9	29	67.2	37.8	34.3	51.6
8	91.0	34.0	18.8	31.1	30	77.0	59.9	30.7	38.3
9	12.6	75.6	82.0	20.0	31	73.5	58.3	34.6	46.7
11	112.7	26.6	18.2	44.9	32	16.8	86.8	58.0	41.7
12	48.2	70.0	94.7	45.7	38	96.5	47.0	14.4	21.8
13	87.3	49.5	52.2	80.6	39	113.3	43.3	13.8	31.1
14	114.1	24.7	13.6	37.1	40	115.9	43.2	16.2	41.3
15	117.0	21.0	15.0	46.3	41	114.5	45.8	16.1	43.9
16	111.1	25.4	20.0	35.6	42	106.2	36.2	15.9	25.1
17	84.0	27.5	19.6	34.0	43	106.6	31.7	21.9	53.6
18	11.7	89.6	95.0	19.5	44	124.9	36.8	13.9	39.9
19	89.6	28.0	74.1	18.2	45	115.5	42.4	18.0	34.0
20	73.2	29.9	22.0	29.9	46	87.5	44.7	20.0	39.5
21	62.1	35.0	41.9	35.8	47	74.7	63.0	24.9	42.6
22	12.6	100.8	82.0	36.9	48	85.0	53.5	16.7	34.2
23	25.7	72.3	87.4	31.0	49	51.3	70.0	41.7	40.0

Note) L : Large trees, M : Middle-sized trees.

CLASSIFYING THE FOREST TYPE BASED ON MULTIVARIATE ANALYSIS

Among the 50 unit blocks of the applied forests of the palm form working system (Cha *et al.*, 1987), data used in the analysis are the measured values of the 42 unit blocks in which the natural broadleaved forests are distributed. Attributes of the multivariate analysis are the number of large and middle-sized trees per hectare, and

the corresponding coefficient of variations, respectively, of each unit block. For the multivariate analysis methods, the steps in this procedure are as follows :

1. The grouping of 42 unit blocks is shown by the dendrogram resulting from a cluster analysis.
2. On the basis of this result, the each unit block is presented by the scatter diagram produced by using the principal component analysis.
3. Based on the dendrogram resulted from cluster analysis and the scatter diagram given by principal component analysis, the mutual relationships between the forest types are discussed from the point of view of forest management.
4. As investigating the validity of classifying the forest type, each unit block is classified into several forest type groups.

RESULTS AND DISCUSSION

Classifying the Forest Type by Cluster Analysis

Cluster analysis is one of the multivariate methods used in numerical taxonomy, a field that uses numerical methods to make classification. The number of groups we want the classification to have determines where we should cut the dendrogram. Deciding where to cut the dendrogram resolves the tradeoff between the desires of detail (many cases) and the desires for generality and simplicity (few cases). The selection of best grouping is therefore subjective (Romesburg, 1984).

In clustering method we used the WPGMA, standing for "weighted pair-group method using arithmetic average", and a squared Euclidean distance as the barometer of a dissimilarity coefficient among the resemblance coefficients.

Attributes used in classifying the forest type are 4 variables of the number of large and middle-sized trees per hectare by photo-interpretation, and the corresponding coefficient of variations, i. e. a data matrix having 4 attributes (Table 1). Fig. 1 shows the dendrogram produced by using the WPGMA clustering method. If we have roughly cut its branches with a horizontal line drawn at step 22, this severs the dendrogram into three branches : the first is cluster of unit blocks consisting of many large broadleaved trees (large number of large trees), the second is cluster of unit blocks with a many middle-sized broadleaved trees, and the third is cluster of unit blocks having a moderately large number of large and middle-sized trees. Assume that we have decided that these clusters are archetypes of three classes of our classification.

Next, to explain in full detail these three clusters, if we have cut with a horizontal line drawn at step 17, these clusters are divided into eight branches, that is, from A to H. Table 2 illustrates the classification and features of forest types resulting from the WPGMA clustering method.

As is evident from the table, firstly, the cluster consisting of many large trees is divided into four branches of A, B, C and D by the differences of the density of the number of trees and the coefficient of variations of each unit block. Judging from the coefficient of variations, cluster A of 11 unit blocks is relatively distributed by the large trees and few middle-sized trees in the unit blocks as a whole, cluster B of 10 unit blocks gives the distribution of the great many large trees with a small coefficient of variation. This means that large trees is uniformly distributed in the unit block, and cluster C and D show the distribution of the moderate number of large and middle

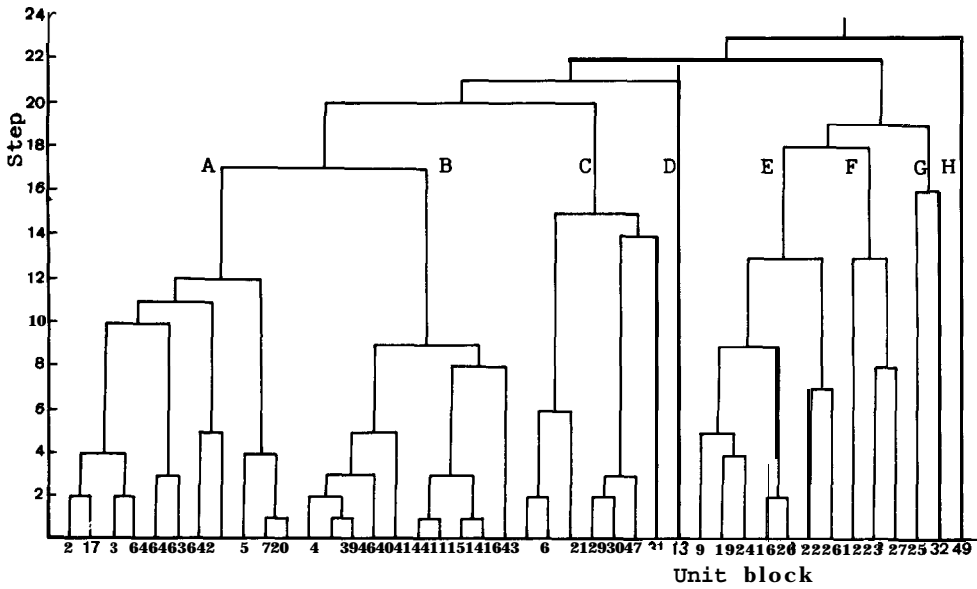


Fig. 1. Dendrogram resulting from a WPGMA clustering method of the data matrix given in Table 1.

trees. Furthermore, cluster D of only a unit block stands somewhat alone. This cluster is distributed by large trees within only a certain part of unit block by the corresponding coefficient of variation, particularly.

Secondly, the cluster with a many middle-sized trees is partitioned into three classes of E, F and G. These three clusters indicate the distribution of very few large trees and are distributed as a concentrated distribution. Furthermore, cluster G of 2 unit blocks is founded by the larger number of middle trees than those of E and F.

Lastly, cluster H is dissimilar to other cluster. This cluster is distributed by middle-sized and large trees having a moderate variation, in general.

As mentioned above, we obtained the eight forest types as the result of clustering method and explained the features of these clusters (8 forest types). In addition, to observe the relationships between the unit blocks of these eight clusters, we will do principal component analysis and plot the component scores.

Classifying the Forest Type by Principal Component Analysis

Principal component analysis is a multivariate statistical technique that is often useful in reducing the dimensionality of a collection of unstructured random variables for analysis and interpretation. It may be helpful to replace a large number of variables by a smaller number of variables or functions of variables without an accompanying loss in the analytical objectives.

As a first step in this analysis, it is necessary to decide which components have any practical significant. Since the units of measurement are not the same, it is necessary to do the principal component analysis based on the correlation matrix. Variables used in this analysis are 4 attributes of the number of large and middle-sized trees, and

Table 2. Optimal forest type grouping for broadleaved forests based on cluster analysis.

Forest type and figures of unit blocks classified	number of trees of each diameter class (trees/ha)	coefficient of variation of each diameter class (%)	Features of diameter class composition and coefficient of variation composition
A	86.0	20.8	many large trees and uniform distribution
2, 3, 5, 7, 8, 17, 20, 38, 42, 46, 48	66.5-106.2	14.4-28.2	
	36.5	30.9	
	27.0-53.5	20.7-39.5	
B	114.7	16.0	great many large trees with a small variation and very few small trees
4, 11, 14, 15, 16, 39, 40, 41, 44, 45	108.2-124.9	13.8-20.0	
	34.7	39.1	
	21.0-45.8	31.1-46.3	
C	74.2	32.6	a moderate distribution of large and middle trees
6, 21, 29, 30, 31, 43, 47	58.3-106.6	21.9-41.9	
	46.6	44.5	
	31.7-63.0	35.8-53.6	
D	87.3	52.2	a concentrated distribution of middle trees
13	49.5	80.0	
E	14.9	85.0	very few large trees and many middle trees
9, 18, 19, 22, 24, 26, 28	11.7-26.4	74.1-95.0	
	88.4	25.2	
	75.6-100.8	18.2-36.9	
F	33.8	87.0	few large trees with a large variation
12, 23, 27	25.7-48.2	78.9-94.7	
	72.1	41.6	
	70.0-74.1	31.0-48.1	
G	17.8	50.7	very many middle trees and very few large trees
25, 32	16.8-18.7	43.3-58.0	
	92.4	28.0	
	86.8-98.0	14.3-41.7	
H	51.3	41.7	large and middle trees with a moderate dispersion
49	70.0	40.0	

* Figures in the upper row show average and those in the lower row show minimum and maximum values.

* Diameter classes consist of middle-sized trees from 22 cm to less than 32 cm and large trees greater than or equal to 34 cm.

* Upper and lower rows of this column correspond to large and middle-sized trees, respectively.

the corresponding coefficient of variations, respectively, as explained the cluster analysis. Table 4 gives the eigenvalues, eigenvectors and the cumulative proportion of the total variance for the first three components, the characteristic roots of the correlation matrix for the four variables given in Table 3 for the following variables :

X(1) : the number of large trees (trees/ha)

X(2) : the coefficient of variation of number of large trees (%)

X(3) : the number of middle-sized trees (trees/ha)

X(4) : the coefficient of variation of number of middle trees (%)

Table 3. Correlation matrix for broadleaved forests variables.

Variable	X(1)	X(2)	X(3)	X(4)
X(1)	1.000	-0.888	-0.857	0.359
X(2)		1.000	0.817	-0.166
X(3)			1.000	-0.280
X(4)				1.000

Table 4. Eigenvalues and eigenvectors for the 3 components of the correlation matrix.

Variable*	Eigenvector for component		
	1st principal component	2nd principal component	3rd principal component
X(1)	0.575	-0.042	0.242
X(2)	-0.549	0.269	-0.533
X(3)	-0.553	0.116	0.808
X(4)	0.247	0.955	0.062
Eigen value	2.827	0.904	0.183
Proportion	0.707	0.226	0.045
Cumulative prop.	0.707	0.933	0.978

* Symbols of variable are shown in Table 3.

The number of factors chosen is usually the number of eigenvalues larger than 1. For this case, three factors are chosen, which contributed 97% of the total variation. As Table 4 shows, the first two components account for 93% of the total variation, and the first three components for 97%. Thus, it appears that two or three components are sufficient to account for most of the variation. By inspecting the coefficients in Table 4, we can interpret the meaning of the components.

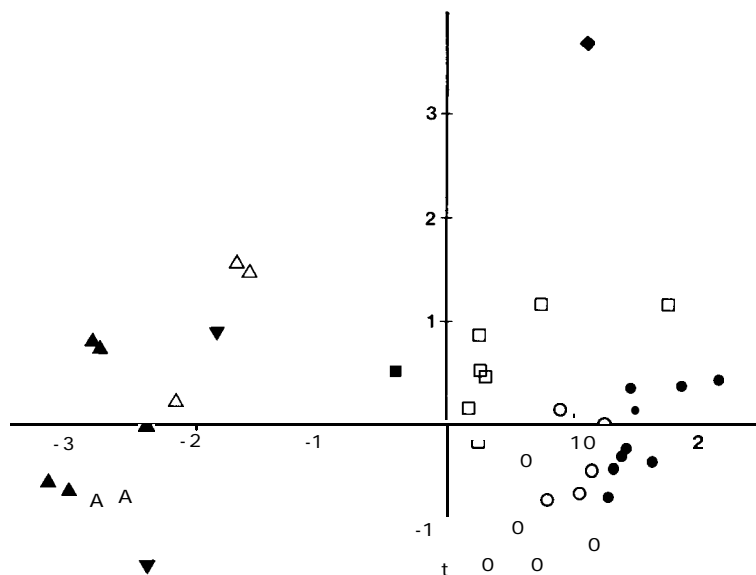
The first component is characterized by positive weight (0.57) for the number of large trees and negative weight (-0.55) for the coefficient of variation of number of large trees, and number of middle trees. This component indicates a contrast between the number of large trees and number of middle-sized trees and hence may be interpreted as a general index of the size of the number of trees.

The second principal component has a high positive weight (0.96) for the coefficient of variation of number of middle-sized trees and hence represents an index of the distribution of middle trees, while the third principal component gives a high positive weight (0.808) for the number of middle trees, thus representing a measure of the number of middle trees per hectare. The above procedure has reduced the number of component from 4 to 3. In addition the three component extracted can be considered as three independent factors of interest.

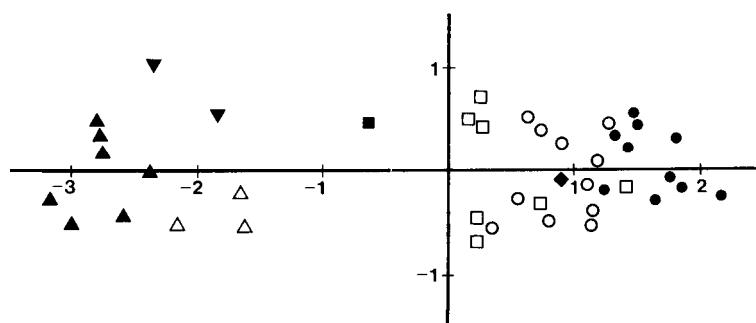
As the first two components account for 93% of the total variation, they can be plotted for each unit block, as in Fig. 2 (a). This scatter diagram suggests the presence

of three major groups, recognizable by the differences of the number of large and middle trees and the coefficient of variation of number of middle trees. The first and fourth quadrants represent the distribution of large trees with a small coefficient of variation. The second and third quadrants are founded by many middle-sized trees.

The first three components account for 97% of the total variation, and are plotted, as illustrated in Fig. 2 (b). This diagram implies that the first and fourth quadrants are characterized by the high density of large trees and coefficient of variation of number of middle trees, and the second and third quadrants are explained by the number of



(a) 1st (horizontal axis) 2nd (vertical axis) principal component



(b) 1st (horizontal axis) 3rd (vertical axis) principal component

Fig. 2. Scatter diagrams of scores of principal component analysis.
(○A, ● B, □C, ◆D, △E, AF, ▼G, ■ H)

middle trees and coefficient of variation of number of large trees. Consequently, there was a trend of increasing the number of large trees from the lower left to upper right corner and conversely, of increasing of middle-sized trees from the upper right to lower left corner in the same quadrant.

As mentioned above, we explained the position relationships of 8 forest types (A, B, C and D composed of large trees, E, F, and G middle-sized trees and H moderate large and middle trees) easily with the scatter diagram of principal component analysis.

In the planning of timber cut of natural broadleaved forests by group-selection cutting system in the near future, the number of large trees and the corresponding coefficient of variation which represents a general index of the distribution conditions of trees are the useful factors. Namely, forest type groups that the number of large trees is larger and the corresponding coefficient of variation is higher should preferentially be cut, and particularly, the order of priority which the forest type (unit block) to be cut should be decided from the point of view of forest management in the same forest type groups.

The aerial photographs provided an overall impression of a richness of forestry which enables the interpreter to obtain information with a greater ease and at lower cost than on the ground survey. As the larger the number of interpretation factors is, the lower the precision of photo-interpretation will be, the selection of the number of interpretation factors can be regarded as the important problem in the photo-interpretation. We obtained the diameter classes of broadleaved forests by the visible crown diameter which can be obtained from photo-interpretation taking the size of an applied area into consideration, and then as the results, performed classifying the forest type based on multivariate analysis, the cluster and principal component analysis.

These analyses present an example of how multivariate statistical techniques may be employed to attempt to improve forestry practice. There are many spheres within the resource management field where these techniques may be useful and an awareness of their capabilities is useful to the forester. Cluster analysis provides a relatively easy and cheap method of taking a first look at multivariate data. Because of the wide variety of clustering algorithms and their general robustness, continuous, discrete, or mixed data can be analyzed with equal facility. Principal component analysis reduces a complex mass of information to workable proportions and is a useful tool in the first stages of any analysis where many data are involved. It can be used as a basis for ordering or classifying the data and, to a limited extent, for allocating samples to different classes.

Results obtained agreed approximately with those expected within the limits of the authors' knowledges and experiences. Thus, it appears that these forest types are sufficient to plan the forest road network and timber cut as only a detail photo-interpretation or ground survey.

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* The title in parentheses is tentative translation from the original Japanese title by the authors of this paper.