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Forest Inventory Combining Densitometer and Sampling Technique in Aerial Photography*

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1. Introduction

Today, forest inventory may be recognized as a type of environmental measurement because foliage covering percentages indicate the degree of nature. There are natural forests, man-made forests, open lands, streams, orchards, cultivated fields and talus slopes etc. on the surface of land. Aerial photographs cover all visible objects and picture the prominent features. Moreover, the distribution, allocation and pattern of all images on the fields are very clear. All images on the monochromatic film have a wide variety of tones varying from light to dark. Densitometer responds to the strongness of tones and gives coresponding waves on recording sheets. The number, height, size and shape of waves give various information about objects. In addition, the record sheet makes a systematic sampling unit and also constitutes the ultimate units. Basically, densitometer techniques and sampling techniques are combined with aerial photographs. This procedure is able to facilitate the automatic observation, calculation and analyzing system of photo images.

2. The outline of mechanics of densitometer

This device consists of light source, focus lens, filter, positive film or print on X-Y carriages, magnifying lens, condenser, variable slit, microscope, focus, electro magnifying tube, photometer source (out put), amplifier and recorder or universal counter. It was made by Applied Electricity Laboratory, Tokyo in 1966. After that, several points were improved and new instruments were added.

Optimum combinations of various gauges of densitometer instruments are shown as follows; slit width 0.08 mm × 0.20 mm, aperture 1.4-4, film carriage speed 5-10 mm/min, sensitivity level 1, filter 2, direct electricity amplifier sensitivity 30, recording speed 120 mm/min, input voltage ratio 8. These numberical indicators, however, must be changed according to the conditions of photograph.

3. The relation between tones and densitometer

In the pre-tests without densitometer instrument by the aid of simple densitometer plate we obtained the following densitometer values; light broadleaved forest 32.5, sun-shining plot 35.0, mountain ridge running from east to west 37.0, *Chamaecyparis*

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(Hinoki) stand 43.8, mountain foot along stream running from east to west 57.5, shaded plot 60.0, *Cryptomeria* (Sugi) stand 66.3, each based on 4 plots. A wide variety of tones varying from light to dark is dependent on the relative position of sun and camera, topography and features of object. In forestry, tree species are the most important features. For example, total means between the peak and the bottom of the densitometer curve based on 111 units are shown as follows; ***Pinus*** (Matsu) 67.70, broadleaved forest 76.06, *Cryptomeria* (Sugi) 81.94. The differences among species are highly significant.

The tones of tree species are related not only to densitometer values but also to densitometer curve. Generally, juvenile stands are lighter than middle age class stands, and also trees at various ages and species have differences in averages, range of densitometer values which is derived from densitometer curve.

Moreover the number of peaks, the width of wave, the number of mode in one wave and the profile of waves should be studied in detail.

4. Densitometer curve in relation to other stand characteristics

The relations of densitometer value to species, age and density, are shown by table 4-1:

Table 4-1. The relations of densitometer value to species, age and density

Plot#	Species	Age	Strip length (m)	Number of trees	Densito-meter	Site
1	*Cryptomeria*	15	130	43	75.8	level
2	〃	35	286	106	80.8	level
3	*Chamaecyparis*	14	113	67	71.3	slope
4	〃	35	100	47	78.0	level
5	*Pinus*	12	137	48	65.3	slope
6	〃	38	162	35	70.9	slope
7	Broadleaved	70	304	95	77.0	slope

From the above data, the following analysis of variances were calculated:

Table 4-2. Analysis of variances

(1) Between species at each age

Source of variation	SS	DF	MS	F
Between species	10408.94	6	1734.82	21.32**
Errors	35309.62	434	81.36	
Total	45718.56	440		

(2) Between species at middle age class

Source of variation	SS	DF	MS	F
Between species	3277.87	3	1092.62	13.47**
Errors	20113.56	248	81.10	
Total	23391.43	251		

(3) Between species at juvenile class

Source of variation	SS	DF	MS	F
Between species	3512.46	2	1750.23	21.24**
Errors	15376.12	186	82.67	
Total	18888.58	188		

At any age classes, ***Cryptomeria***, ***Chamaecyparis***, ***Pinus*** and broadleaved forests have different densitometer values.

Next, we examined the number of modes of densitometer curve. The following table shows the appearing of mode for each species.

Table 4-3. The number of modes of densitometer curve

Species	Unimode	Bimode	Trimode	Multimode
Cryptomeria	29	10	1	0
Chamaecyparis	14	12	2	1
Pinus	19	14	3	0
Broadleaved	3	4	3	1

The Chi-square based on 9 degrees of freedom is 23.36 and significant. This shows that the different species have different types of curve.

The correlation coefficient between the number of peaks of densitometer curve and the actual number of trees is 0.94 which is highly correlated as shown in the following table.

Table 4-4. The number of peaks of densitometer and the actual number of trees

	Cryptomeria		*Chamaecyparis*		*Pinus*		Broad-leaved
	J	M	J	M	J	M	M
Number of peaks of densitometer	40	94	51	36	39	30	58
Actual number of trees	43	106	64	47	48	35	91

J : Juvenile age
M: Middle age

The densitometer curves have the following 3 important characteristics;

(i) average height of densitometer curve, (ii) the number of modes of a densitometer curve, (iii) the number of peaks of the densitometer curves in unit length. The combination of these represents the condition of the various species forest at different ages.

5. Relation between volume of stand and the profile area of densitometer

We tested several regression equations to estimate stand volume. Instead of the base length of densitometer waves, number of peaks, and frequency of cycle, we decided on the area of the profile of densitometer as independent variable. The reasons are; (i) it is similar to the stand profile, (ii) it can be measured by the universal counter automatically, and (iii) it summarizes all characteristics of densitometer.

When independent variable x is the profile area of densitometer curve and dependent variable y is the stand volume on the strip length corresponding to fixed time unit, by using the digital timer and digital recorder, the following volume regressions are calculated.

10 sec unit; $Y=10.5577-0.6705x$, $r=-0.6133$

20 sec unit; $Y=22.4070-0.7323x$, $r=-0.6982$

30 sec unit; $Y=38.1836-0.9495x$, $r=-0.7220$

40 sec unit; $Y=50.3029-0.9429x$, $r=-0.8363$

The above results are figured out from the data of *Cryptomeria* stands comprising 15, 20 and 56 year-old-trees. The total length of strips and the time of measurement of densitometer are 559.7 m and 318.6 sec respectively, then average measurement strip length per sec is 1.757 m.

6. The estimation of the forest percentage by double sampling for stratification

In double sampling, the large sample is the stratification of the level of densitometer and subsample is the indentification within each stratum. For example: 20 contact prints are selected as large sample systematically from 308 photographs and 2 densitometer strips run on each print. The recording sheet has 111cm length corresponding to one side 18cm of the contact print. According to the densitometer curve the 111 units are classified into 4 strata A, B, C and D as shown below:

Table 6-1. Four strata of densitometer levels

Stratum	Densitometer	Representative features
A	under 50	the lightest part; ground 15, open land, field 35, cutting area 40, grass, light broadleaved forest and *Chamaecyparis* 45 etc.
B	50 - 70	light forests; broadleaved forests, shaded grassland, open land 60, *Pinus*, *Chamaecyparis* 70 etc.
C	70 - 85	dark forests; shaded broadleaved forest 75, *Cryptomeria* 85 etc.
D	85 - 100	the darkest part; old *Cryptomeria* 90, shaded cliff 95 etc.

For large sample, the percentages of strata are

$$A;\ w_1=\frac{1112}{4440}=0.2505$$

$$B;\ w_2=\frac{2549}{4440}=0.5741$$

$$C;\ w_3=\frac{658}{4440}=0.1482$$

$$D;\ w_4=\frac{121}{4440}=0.0273$$

For subsample, 5 prints are drawn from large sample and each unit is indentified as forest and non-forest. The summary is shown as follows:

Table 6-2. The number of units of forest and non-forest in subsample

Stratum	A	B	C	D	Sum
Forest	196	478	128	29	831
Non-forest	192	83	4	0	279
Total	388	561	132	29	1110

Forest percentages in each stratum are

$$A;\ p_1 = \frac{196}{388} = 0.505$$

$$B;\ p_2 = \frac{478}{561} = 0.852$$

$$C;\ p_3 = \frac{128}{132} = 0.969$$

$$D;\ p_4 = \frac{29}{29} = 1.000$$

Then the total forest percentages are

$$p_{st} = \sum w_h p_h$$

where p_{st}: estimated total forest percentage by stratified sampling

h: stratum.

That is

$$p_{st} = 0.2505 \times 0.505 + 0.5741 \times 0.852 + 0.1482 \times 0.969 + 0.0273 \times 1.000$$
$$= 0.7865$$

Its variance is calculated from the number of ultimate units of subsample of h stratum;

$$V(p_{st}) = \sum \frac{w_h^2 p_h q_h}{n_h - 1}$$

Finally, we obtained 78.7 ± 1.1 as the estimation of the forest percentages.

This method has been applied to mountainous Kyushu Island and the result is shown as table 6-3:

Table 6-3. Forest area percentages of seven districts

Name	Total area (ha)	Total photographs	Sample photographs	Forest area percentages	Error (%)
Mikuni-toge	2100	44	10	68.54	3.29
Kita-aso	13700	64	10	39.95	2.90
Minakami	8300	111	15	70.00	1.78
Kitaura	1488	16	5	76.51	1.92
Gokasho	3625	45	10	67.89	2.51
Kamishiiba	17000	71	10	75.84	2.51
Suki	2458	37	10	68.22	2.46

Error at 95% confidence coefficient

7. Total volume estimation

Two double sampling methods, double sampling for stratification and double sampling with regression, are used for the estimation of forest volumes. This procedure is explained as three steps below;

(i) Forest percentage estimation from the double sampling for stratification,

$$p_{st} = \sum w_h p_h$$

$$V(p_{st}) = \sum \frac{w_h^2 p_h q_h}{n_h - 1}$$

(ii) Volume regression from small sample in double sampling with regression,

x: profile area (cm^2) per 10 sec unit

y: volume (m^3) per ha,

regression equation (for example),

$$Y = a + b(x - \bar{x})$$
$$= 186.2289 - 16.5454(\bar{x}_L - 9.8787)$$

mean of large sample in densitometer profile area,

$$\bar{x}_L = \frac{\sum(x)}{\sum(n)}$$

n: the number of ultimate units of large sample,

variance of Y,

$$V(Y) = V(a) + b^2 V(x) + V(b)(\bar{x}_L - \bar{x}_s)^2$$

(iii) Total estimation,

forest area,

$$A_f = A \times p_{st}$$

$$V(A_f) = A^2 V(p_{st})$$

where A: the total area,

total volume,

$$M = A_f \times Y$$

$$V(M) = A_f^2 V(Y) + Y^2 V(A_f)$$

The above mentioned method seems possible to apply for forest inventory work but the ones who are going to use it have to keep in mind that it might have photogrammetrical error such as the curvilinearlity of densitometer line. However, this error and bias of sampling techniques seems to be small, because the ultimate unit on recording sheet corresponds to 1 unit of densitometer line on contact print.

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摘　　　要

今日，森林調査は自然度を示す森林被覆度としての一種の環境測定と認められる．空中写真の濃淡色調のコントラストに対する濃度計測と，その濃度計測線に対する標本調査法を組合せることにより，森林環境測定としてその自動計測化を指向した森林調査法につき，従来から実施してきた種々の研究成果をまとめたものである．

その内容は濃度測定装置の機構，色調と濃度の関係，濃度波形と林分特性の関係，とくに樹種，林令などとの関係，林分材積と濃度波形側断面積の関係，層化のための二重抽出法による森林率の推定，およびその実例，2つの二重抽出法を併用した材積推定などを概説した．