空中写真濃度計測による森林蓄積の推定に関する研究

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バージョン：

Research on the Estimation of Forest Volume by Densitometer Measurement in Aerial-photographs.

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Summary

The basic principles of the estimate of forest volume due to the measurement of densitometer in aerial-photographs are founded on the recognition of the pattern for the variation of contrast coming from light and dark tone of photography.

In the forest aerial-photographs, the refected light and the wave length from forest component element, species, age, density etc. are recorded and described exactly on the film and print. Therefore, by means of measurement with photo densitometer instruments which have optical and mechanical devices, the relationship among the densitometer and volume, number of trees etc. should be studied.

At first, in chapter 1, after the examination of the volume estimate by interpretation of aerial-photographs, the author has shown that the densitometer system is superior to the interpretation of aerial-photographs in the volume estimate.

Briefly speaking, according to the above reasons, in the interpretation some difficultes are confronted. The first is the measurement of tree height on the photograph. The second is the existence of high variation amongst estimated values of crown diameter, tree height, the number of trees etc., due to experiences and skilfulness of interpreter. The third is the different sizes of plots which effect largely the efficency of the measurement. The fourth is that the interpretation has the limit of automatic measurement. However, densitometer system can be developed mechanically to automatic measurement to improve accuracy in future. Depending upon the relationship between the factor of measurement of interpretation and densitometer measurement, the auther proposed the possibility of the estimate of forest volume by means of the densitometer from the pretest and comparing examination. The characteristics of the densitometer measurement are considered as the automatic operation and combined with the sampling techniques.

Chapter 2: Treating the basic experiment. There are photomal electronic sources, photomal light reciever, photo electronics mechanics, operation system, direct current amplifier and recorder in main installations. The test of the density step tablet, photo tone scale and crown density scale were carried out by the densitometer. The combination tests of each instrument gauge were replicated. From the results of a lot of examination, it becomes clear that the density step

tablet, photo tone scale and crown density scale are corresponding to the exact measurement value of the densitometer. The best combination of each instrument gauge in the main part of the densitometer installation is shown as follows; the width slit is 0.04 mm – 0.08 mm (for x direction) × 0.10 mm – 0.20 mm (for y direction), the iris diaphragm of lens is 1.4, data carriage speed is 5 mm – 10 mm/min, sensitivity range ×1, the number of filters 2–1. In the direct current amplifier, the best combination is the sensitivity range ×30 – ×10. For recording, chart speed is 120 mm – 240 mm/min and input voltage range is 0.1 V – 1.0 V etc.

For the automatic measurement of the densitometer, the universal counter and A-D converter were added. By means of their uses, the measurement of the number, cycle and profile area of densitometer waves became possible. Moreover, digital timer and digital recorder were combined newly to progress these operations automatically. Operations became almost automatic. In consequence of these operations, the time unit base came in place of the length or area unit base in the survey system. In other words, the time unit was applied to measure the length of strip or densitometer line. It may be one of characteristics.

Moreover, the reflected type of measurement apparatus has been used in stead of the transpierced type. The reflected type measurement made the possible use of prints. Therefore, treatments became easier and more convenient than those of positive film.

Chapter 3: The experimentation of use of models and the analysis of densitometer waves for actual stand were carried out. Basic analysis for the densitometer values of the number of trees (density), crown diameter, species and age etc. were examined. Consequently, the relationships between the number of trees and the number of peaks of the densitometer waves, and between the crown diameter and the base length of the densitometer waves were examined and computed to measure the degree of correlation. For the identification of species, *Cryptomeria* (Sugi), *Chamaecyparis* (Hinoki), *Pinus* (Matsu) and broadleaved forests, average level of the densitometer and the typical type of the shape of waves were decided. For ages, young, middle and old stands, the level of the densitometer were investigated.

The relationship between the number of trees (y) and the number of peaks of the densitometer (x) was shown as follows:

$$Y = 4.4058 + 1.1585\,x, \qquad r = 0.939$$

The correlation coefficient was very high.

The relationship between the densitometer size of the crown diameter measuring scale (x) and the basic width of the wave of the densitometer (y) was shown as follows:

$$Y = -0.6309+8.0655\,x, \qquad r = 0.995$$

The correlation coefficient was very high.

In model experiment, four kinds of crown shapes, cone, ellipsoid, paraboloid and hemisphere, were used. In each case, the diameter had seven levels from 2 cm to 8 cm, and the height has 24 levels from 14 cm to 24 cm. The total number of models was 406. From these models, 14 models including large, middle and small size were chosen and taken photographs. The relationship between the size of model (y) and the width of the corresponding densitometer wave (x) was as follows:

$$Y = 0.0954+2.1123\,x, \qquad r = 0.999$$

The correlation coefficient was very high.

Actually the condition of crown diameters of the stand are very complicated, but from the above model experiment, the measurement of crown diameter may be possible to be measured with the wave width of the densitometer curve.

Crowns of trees standing in a line which runs parallel with sunshine direction were best to measure the size of crown diameter by densitometer curve.

The relation of densitometer value to species and age were examined with main species, *Cryptomeria*, *Chamaecyparis*, *Pinus* and broadleaved tree. The densitometer values due to the different species were significantly different and the shape of densitometer curve was different by species. The characteristics of the species appeared in the type of curve, i.e. unimode, bimode, triplemode and multiplemode. In the testing of χ^2 they were highly significant.

Chapter 4: The relation between volume of stand and the densitometer measuring values. At first, the examination of accuracy of correspondence between field survey strip line and densitometer line on the photograph was carried out. From the result of examination, the radial line from principal point was desirable, because the positive and negative displacement possibly occured along the radial line. Even though these errors were small, basically the displacement problem was very important. In future, this point should be improved.

For the strip which runs through *Cryptomeria* stand, in 67 compartment with 210 m length and 10 m width at Ebino, the examination of the volume based on 10 m×10 m ultimate unit corresponding to the densitometer curve was carried out. The following regression equation was obtained.

$$Y = -0.577+0.741\,x_1+0.199\,x_2, \qquad SE = \pm 0.269\ \mathrm{m}^3$$

where x_1: average base width of densitometer wave
x_2: the number of peaks of densitometer curve
Y: volume per 10 m×10 m ultimate unit

The percentage of the standard error in the average volume per plot is 12.3.

Next, for the large area of *Cryptomeria*, *Chamaecyparis*, *Pinus* and broadleaved forest, 68, 69 compartment at Ebino, the double sampling survey with the densitometer strips were tested. 7 densitometer strips were drawn as the first sample, and 3 field strips were surveyed as the second sample. In this case, the size of the ultimate unit was 4 m×50 m and the independent variable of the volume regression was limited only to the base width of densitometer wave. The correlation coefficient of volume and width of wave was 0.751. The regression equation was shown as follows:

$$Y = 4.1014 + 1.7184\ (x - 3.4029), \qquad SE = \pm 0.2499\ \mathrm{m}^3$$

The total number of plots of large sample was 89 and the large sample average of width of wave (x) was 3.3073 mm. Then the volume estimate per ha was 393.71 m³. Total volume estimate of the whole area 95.54 ha with probability 95 % was

$$92.54 \times (393.71\ \mathrm{m}^3 \pm 2 \times 24.99) = 36433.92\ \mathrm{m}^3 \pm 4625.15\ \mathrm{m}^3.$$

After this examination, the relation between the volume and the period of densitometer wave and the relation between the volume and frequency of densitometer wave were tested. These correlation coefficients were about ±0.6.

Finally, the profile area of densitometer wave was decided as the independent variable of the volume regression. This concept came from stand profiles. The linear relationships between volume (y) and the profile area of the densitometer waves (x) were calculated for *Cryptomeria*, *Chamaecyparis*, *Pinus*, natural broadleaved forests. These regression equation showed high correlation coefficients. The measurement of the profile area of densitometer waves can be done automatically and will be connected to computer system in future.

Chapter 5: Depending upon the above principle and examination, the application for the volume estimation of the large area forests by densitometer was carried out.

For the volume estimation of the large area forests, two double sampling methods, one for the stratification of the densitometer and another for volume regression estimation, were applied.

For example, 18 cm×18 cm print which is called number 6-course number 9-aerial-photograph, Kirishimayama district, Yama-456, for Sakakura, Kuroshika and Kawazoi natural forests belonging to Ebino Forestry Office, covers 1254.22 ha, total area. On this print, 10 densitometer lines with equal interval from east to west were measured. On these densitometer recording sheets, four levels of brightness of densitometer (A, B, C and D) were decided upon the ultimate unit. If h is denoted as stratum, n' is the total number of ultimate units of the first samples and n'_h is the number of ultimate units belonging to h stratum, then the percentage of h stratum is $w_h = \frac{n'_h}{n'}$. 5 sub samples of densitometer line were drawn from the first 10 densitometer strips, then forest or non forest was identified by the interpretation of sub sample.

The forest percentage is $p_h = \frac{n_{h_i}}{n_h}$, where n_h is the total number of unit of second sample at h stratum and n_{h_i} is the number of units of second sample as the forest at h stratum. Then total forest percentage is $p_{st} = \sum w_h \cdot p_h$, where p_{st} means the percentage of forest by stratified sampling. And its variance is $V(p_{st}) = \sum \frac{w_h^2 \, p_h \, q_h}{n_h - 1}$, where $q_h = 1 - p_h$. In this case, the total forest area percentage was

$$100 \times [0.7369 \pm 0.0109] = 73.69\,\% \pm 1.09\,\%.$$

Next, due to 5 densitometer lines, the profile area of the densitometer waves (x) were measured and also the volume (y) was investigated from the forest inventory register. Then, the regression equation was decided as below:

$$\bar{Y} = \bar{y} + b(\bar{x}_L - \bar{x}_s)$$
$$= 186.2289 - 16.5454(\bar{x}_L - 9.8787), \qquad r = -0.703$$

where b : regression coefficient
$\bar{x}_s$: the small sample mean, profile area of densitometer wave of second sample
$\bar{x}_L$: the large sample mean, total mean profile area of densitometer wave of large sample
$\bar{y}$: total average volume per ha by small sample
$\bar{Y}$: the estimate volume per ha for total samples

Now, large sample mean from 10 densitometer lines, as the profile area,

$$\bar{x}_L = \frac{\sum(x)}{\sum(n)} = \frac{5983.23}{540} = 11.0801$$

Then,

$$\bar{Y} = 186.2289 - 16.5454\,(11.0801 - 9.8787) = 166.3513 \text{ m}^3$$

The variance $\bar{Y}$:

$$V(\bar{Y}) = V(\bar{y}) + b^2 V(\bar{x}_L) + V(b)(\bar{x}_L - \bar{x}_s)^2$$
$$= 178.4017 + 273.7496 \times 0.0316 + 40.0855 \times 1.4432 = 244.8960$$

Standard error:

$$SE(\bar{Y}) = \sqrt{V(\bar{Y})} = \sqrt{244.8960} = 15.6492 \text{ m}^3$$

Error percentage:

$$e(\%) = \frac{SE}{\bar{Y}} \times 100$$
$$= \frac{15.6492}{166.3513} \times 100 = 9.41\,(\%)$$

If the area of covering print is assumed,

$$A = L \times L$$
$$= 3541.5\ \text{m} \times 3541.5\ \text{m} = 1254.22\ \text{ha}$$

where $L = l \times S = 0.18 \times 19675 = 3541.5\ \text{m}$

l: the length of one side of a print in m

S: the scale of this photograph

The forest area:

$$A_f = A \times p_{st}$$
$$= 1254.22 \times 0.7369 = 924.23\ \text{ha}$$

The total volume of the total forest area:

$$V = A_f \times \bar{Y}$$
$$= 924.23 \times 166.3513 = 153746.8620\ \text{m}^3$$

And the variance of this total volume:

$$V(V) = A_f^2 V(\bar{Y}) + \bar{Y}^2 V(A_f)$$
$$= (924.2347)^2 \times 244.8960 + (166.3513)^2 \times 186.5658$$
$$= 214355350.1457$$

where $V(A_f) = A^2 V(p_{st})$
$$= (1254.22)^2 \times 0.0001186 = 186.5658$$

The standard error and this error percentage were estimated as follows:

$$SE(V) = \sqrt{V(V)}$$
$$= \sqrt{214355350.1457} = 14640.8794\ \text{m}^3$$

$$e(\%) = \frac{SE}{V} \times 100$$
$$= \frac{14640.8794}{153746.8620} \times 100 = 9.52\,\%.$$

Then, for the subjected print, the estimated forest area was 924.23 ha and the volume including *Cryptomeria*, *Chamaecyparis*, *Pinus* and broadleaved forests was in total, 139105.98 m^3～168387.74 m^3 with inference error percentage 9.52 %. The estimate of the large area forests will be obtainable with the densitometer devices and must be developed in future.