TECHNICAL NOTE

PROVISIONAL AERIAL PHOTO STAND VOLUME TABLES FOR INTERIOR BRITISH COLUMBIA

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Introduction

The Province of British Columbia has a total area of 234 million acres, of which 137 million acres (214,062 square miles) are forested. With the ever-increasing demand for information concerning this forest resource, it was felt that the use of aerial photographs could be an aid in procuring timber volume estimates, just as they had been an aid in producing maps for many years. Since 1953 members of the Forest Surveys Division, B.C. Forest Service, have studied this problem and attempted to adapt the methods of others to the conditions in this province.

Aerial photo stand volume equations, relating **gross** volume per acre with measurements of stand height and density on the aerial photographs, have been prepared for two Interior zones. The aerial photographs used on these projects were flown at 19,000 feet above sea level, using a camera with an 8 inch focal length lens. The negatives were enlarged 1.85 times to produce a print at a scale of 1:15,840.

The findings reported here are based on 414 double samples established in 1955 in Zones 4 and 6. Future work is now planned to produce similar aerial photo volume equations for each of the five remaining zones which divide the province according to species occurrence and climate. As progress is made in double sampling and in developing better methods, the precision of the aerial photo volume equations can be expected to increase.

Results to Date

Work on this problem has proceeded as quickly as suitable photography and manpower have become available. To date, Zone 4 (Central Interior) and Zone 6 (South-east Interior) have been sufficiently well covered by double sampling to derive stand volume equations. For the sake of simplicity, a linear relationship was assumed to exist between gross volume **per acre** and each of the independent variables, height and density respectively. Each equation was constructed by least squares solution of a linear regression, of the form:

$$V = b_0 + b_1H + b_2D$$

where:

V—is the gross volume **per acre** in 10's of cubic feet of living merchantable trees. Determined by ground sampling.

H—is the average height of dominant trees as measured with a parallax bar on aerial photographs.

D—is the crown density expressed as a percentage of ground covered, as determined on aerial photographs by comparison with a dot-type crown density scale.

b_0 , b_1 , and b_2 are coefficients derived from the data by the least-squares method.

Values of the regression coefficients and other pertinent statistics are shown in Table 1.

TABLE 1
 LINEAR REGRESSION ON GROSS VOLUME (10'S OF CU. FT.) PER ACRE
 ON PHOTO HEIGHT AND DENSITY

	Mature Coniferous	Immature Coniferous	Lodgepole Pine and Deciduous Species All-Ages
ZONE 4			
Regression constant, b_0	+ 98.5	-129.9	-113.5
Coefficient of Height, b_1	+ 3.38	+ 5.53	+ 3.33
Coefficient of Density, b_2	+ 0.629	- 0.378	- 0.096
Multiple correlation Coefficient R^2 V.H.D.	.50	.64	.46
Partial correlation Coefficient R^2 V.H.	.46	.64	.46
Number of double samples	165	44	37
ZONE 6			
Regression constant, b_0	+261.8	- 78.3	- 90.4
Coefficient of Height, b_1	+ 2.68	+ 1.54	+ 2.85
Coefficient of Density, b_2	- 2.927	- 1.472	+ 0.116
Multiple correlation Coefficient R^2 V.H.D.	.28	.51	.66
Partial correlation Coefficient R^2 V.H.	.18	.33	.39
Number of double samples	119	23	16

Discussion of Results

The results in Table 1 require explanation.

1. The double samples in mature and immature coniferous stands are not fully representative of all stands occurring in the respective zones. In Zone 4, double samples were mainly in spruce (*Picea glauca*)-balsam (*Abies lasiocarpa*), occasionally in fir (*Pseudotsuga taxifolia*) or fir-cedar (*Thuja plicata*)-hemlock (*Tsuga heterophylla*) stands. In Zone 6, samples included Douglas fir, cedar, hemlock, balsam, spruce (*Picea Engelmannii*) and larch (*Larix occidentalis*), but not yellow pine (*Pinus ponderosa*). The range of sites and ages within each zone was generally broad. Pure lodgepole pine (*Pinus contorta* v. *latifolia*) and pure deciduous stands were combined simply because of the scarcity of samples in each, and their general lack of resemblance to the coniferous stands. Support for this action is given by Karl Moessner (Intermountain Forest and Range Experiment Station, Ogden, Utah) who is of the opinion that the same aerial photo volume table can be applied to lodgepole pine and aspen stands.
2. The inclusion of stand density as a variable, or the assumption that its relation to gross volume per acre is linear, is open to question. As can be seen from Table 1, the correlations of gross volume per acre with height alone are generally equal to, or only slightly inferior

FIGURE 1.

GRAPH SHOWING PHOTO VOLUME ESTIMATES
FOR MATURE CONIFEROUS STANDS
IN ZONE 4

to, the multiple correlations with both height and density. The analysis of variance and F-test indicate that the added effect of density is insignificant in nearly all cases. The effect of density could, perhaps, be increased if the square of density were introduced as a variable. The square of density was not tested as a variable because it was thought that the added complexity of application would outweigh any slight increase in accuracy.

3. It will be noted that some of the correlation coefficients are of a low order, probably because of the wide variation in gross volume per acre within the zone and because several photogrammetrists, each with a different "personal factor", worked together. However, as will be shown, the equations are corrected in the course of any survey to account for local peculiarities of photography, local stand conditions, and any tendency of a single person to overestimate or underestimate height and density. The presence of a favorable correlation within the equation itself is, therefore, desirable but not critical provided that the correlation obtained between ground volume per acre and photo estimated volume per acre in a local area is favorable. In practically all local applications, the final correlation of ground volumes per acre with photo estimates of volume per acre was greatly increased. For example, when ground volumes $11.1'' + d.b.h.$ and photo estimates based on the Zone 4 equations were compared in the vicinity of Babine Lake, the resulting correlation coefficient was .82.

Presentation of the Photo Volume Equations

A graphic presentation of the volume equation was found to be most convenient in application. The volume equation is solved for three values of height for each density class, and the results used to construct a graph as shown in Figure 1 (Photo Volume estimates for Mature Coniferous stands in Zone 4).

Application of a Photo Volume Graph

Given a tract of forest requiring a gross volume estimate by timber types, the use of the photo volume graph becomes a **problem in double sampling**. Only for the most preliminary estimates may volumes be read directly from

the zone graphs. Field sampling is necessary to obtain a local correction factor. Briefly, the steps involved in application are as follows:

1. Locate a relatively large number of photo samples in each forest type, preferably by a random system. Measure the height and density of each sample on the photographs and read the corresponding gross volume per acre from photo volume graph.
2. Designate a proportion of the above photo samples for ground occupation and measurement. (1)
3. The gross volumes per acre from the aerial photo samples are then combined with the volumes per acre obtained from the ground sampling to produce a local photo volume/ground volume regression for the entire tract. This regression in turn is used to give an adjusted gross volume per acre for each forest type in the tract. The formulae are given below.

$$(i) \ b = \frac{\frac{\sum GP - \frac{\sum G \sum P}{N}}{\sum P^2 - \frac{(\sum P)^2}{N}}}{N}$$

where: G = volume per acre from ground samples in the tract.

P = volume per acre from photo samples in the tract.

N = Number of ground samples in the tract.

$$(ii) \ G = \bar{G} + b(P - \bar{P})$$

where: G = adjusted photo volume per acre for a forest type.

$\bar{G}$ = Average volume per acre of all ground samples in the tract.

b = is derived from equation (i) above.

P = average photo volume per acre for single samples in a forest type (from photo volume graph).

$\bar{P}$ = average photo volume per acre for all double samples in the tract.

Following is an example of an application of the Zone 6 Photo Volume Graph to a specific forest area. A portion (25,800 acres) of the Cochran Creek drainage, a tributary of the Kootenay River, was chosen as the example. Thirty-six double photo-ground samples and 239 single photo samples were established in the test area.

The double samples were used to develop a local photo volume/ground volume regression. Solving equation (i) above for the tract gave a "b" value of 1.3294. This value can now be used to determine the photo volume estimate for any forest type in the tract. The calculations for the photo volume estimate of a single mature coniferous type of 1950 acres in area are shown.

In the forest type used as an example there were seven double photo-ground samples and eighteen single photo samples (i.e. a total of twenty-five photo samples and seven ground samples). The thirty-six double photo-ground

samples in the tract had an average gross volume per acre by ground sampling of 3,247 cubic feet 11.1" + d.b.h. ($\bar{G}$), and an average volume per acre by photo estimate of 2,799 cubic feet ($\bar{P}$). For the single type, the average volume per acre by photo estimate was 3,190 cubic feet (P), and the average volume per acre by ground sampling was 3,603 cubic feet. Solving equation (ii) above we have:

$$\begin{aligned} G &= \bar{G} + b(P - \bar{P}) \\ G &= 3247 + 1.3294(3190 - 2799) \\ G &= 3767 \text{ cubic feet per acre (11.1" + d.b.h.)} \end{aligned}$$

It should be noted that, without the local correction, there would have been a substantial difference between the average gross volume per acre by photo estimate and the average gross volume per acre by ground sampling for the type.

The error calculations are not shown but the results for the single mature coniferous type in question are:

$$\begin{aligned} \text{Ground estimated volume per acre (11.1" + d.b.h.) (7 samples)} &= \\ 3603 \pm 1136 \text{ cu. ft. (2SE)} \end{aligned}$$

$$\begin{aligned} \text{Double sampling estimate of volume per acre (11.1" + d.b.h.)} \\ \text{(25 samples)} &= 3767 \pm 714 \text{ cu. ft. (2SE)} \end{aligned}$$

The correlation of ground volumes per acre with photo estimates of volume per acre for this mature coniferous stand was .68 as compared with .28, the correlation coefficient for all mature coniferous stands in Zone 6. Based on ground sampling, the average gross volume per acre 11.1" + d.b.h. for the type has a 31.6% error (at 2SE) whereas the error of the photo volume estimate is 19.0% (at 2SE). To obtain the same accuracy with ground sampling alone would have required eleven additional samples. Thus the use of the photo volume graph, **plus the local correction**, resulted in a substantial improvement in the volume estimate for the type.

Conclusions

Having established a local photo volume/ground volume regression, there are many advantages in photo volume estimating. The most obvious advantage is the saving in time and money. From forty to sixty photo samples can be measured in the same number of man-hours required to measure one ground sample. Also photo sampling is not dependent upon weather conditions as is ground sampling.

Furthermore, conventional ground sampling is most reliable when the samples are located by a random or nearly random system. This often necessitates sample locations difficult to reach on the ground. Under a double sampling system, "purposive" selection of double sample locations (in this case, the choosing of a roughly equal number of samples in each photo-measured height class) is not only permissible but desirable, in that it obtains a "b" value of satisfactory precision with **fewer samples than required with a random system**. "Purposive" selection of double samples can be combined to some degree with selection for convenience. If some ground samples

must be located in each type to provide information on species distribution, cull factors, and timber quality, they can be located in the most accessible portions of the type.

The advantages of photo volume estimating should be of value to those concerned with the administration of forest management units. A relatively small number of properly chosen ground samples will permit the development of photo volume/ground volume regression for the unit. Having this regression, volumes can be estimated for any combination of timber types within any portion of the unit without further field work.

References

1. SCHUMACHER, F. X. and R. A. CHAPMAN, 1948. Sampling methods in forestry and range management. Duke University School of Forestry. Bulletin 7, 196-199.