*Problems and Potential Uses of Photo-Mensurational Techniques for Estimation of Volume of Some Immature Stands of Douglas Fir and Western Hemlock**

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ABSTRACT: *This is a report on what was to have been a large and comprehensive study of this important problem. Its scope has been limited by lack of funds for the training and hiring of interpreters.*

Many of the topics summarized in this paper should be the subject of individual and detailed reports. A generalized approach has been chosen in order to outline our progress to date and in order to illustrate the complications and limitations in the application of photo-mensurational techniques.

INTRODUCTION

THE study was initiated in 1954 at the University Research Forest, Haney, B. C., in co-operation with Dr. Lyle Trorey Mr. Helmut Swantje, and Messrs. L. Eliel and F. J. Churko of Aero Surveys Ltd. It covered the problems and potential uses of photo-mensurational techniques for estimation of volume of some immature stands of Douglas fir and western hemlock.

In the early summer of 1954, photographs were taken at three altitudes with both 12 and 20 inch focal-length cameras by Aero Surveys Ltd. In the fall of that year, Mr. W. Hall of the Surveys and Mapping Division of the Provincial Lands Service had the study area photographed from three altitudes with a 3.25 inch focal-length camera. In the summer of 1955, the Western Division of the Photographic Survey Corp. Ltd. photographed the study area with a 12 inch focal-length camera. Ground control was provided by single trees and plots measured by staff and students of the Faculty of Forestry of the University of B. C. Funds for assistants were provided by Mr. Prentice Bloedel and by the University of British Columbia. These funds, the assistance of all co-operators, and the generous help and advice of Dr. Trorey are gratefully acknowledged.

The area studied is on the southwest side of the University Research Forest at Haney. The stands range in average age from 55 to 75 years, in site index at 100 years from 80 to 160 feet, and in average height from 60 to 140 feet. Total cubic-foot volumes of individual 0.4-acre plots range from 2,200 to 20,200 cubic feet. On the same plots, merchantable board-foot volumes by the B. C. log rule range from 2 M f.b.m. to 102 M f.b.m. per acre. Species present are Douglas fir, western hemlock, and western red cedar, varying widely in proportion. Topography is rolling to rough with many localized rock outcrops and a complex drainage pattern. Crown canopies are irregular but generally dense. Stand openings are invaded rapidly by tolerant tree species or by shrubs such as salmonberry, huckleberry, and salal. Height, density, and variability of such stands have hindered development of intensive uses of aerial photographs in cruising.

MAPPING AND CONTROL OF INVENTORY

The uses of aerial photographs in mapping and control of inventory are gaining

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increasing acceptance in British Columbia. Aerial photographs are employed generally in preparation of base maps, in topographic mapping, and in field location of plots and strips. The use of photos to supplement ground typing and to pre-stratify areas to be cruised is increasing. Determination of homogeneous forest types or strata through typing prior to cruising may result in important reductions in costs of inventory. For example, the standard error of the mean (SEm) of 46 0.4-acre plots established within the study area at Haney was 6.9 per cent without typing. Arrangement of plots in 3 blocks reduced the SEm to 6.4 per cent. If these plots could be typed perfectly into three volume classes the SEm of all plots would be reduced to 2.6 per cent and with four volume classes to 1.9 per cent. Direct measurements of height, crown width, and crown closure; comparison with stereograms; or wholly subjective assessment may be used to gain all or part of the advantages of stratification for control of inventory.

Correlations among Measurable Factors and Volumes per Acre

In order to assess the possible uses of photo-mensurational techniques in intensive cruising, it is necessary to determine correlations between stand volumes and the measurable variables. These correlations, or the degree to which a dependent variable may be accounted for by one or more independent variables, may be compared directly when degrees of freedom are equal. The correlation coefficient "r" expresses degree of association from 0 for none to 1 for perfect correlation.

FIELD ESTIMATES OF STAND VOLUME

Correlations among total cubic-foot volumes (Y) and variables measurable on the ground were determined for 44 0.4-acre plots. Correlation coefficients were 0.82 for basal area (BA), 0.84 for stand height (H), and 0.90 for basal area times stand height ($BA \cdot H$). The multiple correlation coefficient for volume with these variables derived from $Y=0.28\ BA+0.62\ H+0.04\ BA \cdot H-45.44$ was only 0.91. This is little better than the simple correlation that exists between volume and basal area times height. It is unlikely that even the best of photo-measurable variables can provide an equal degree of association. The correlation coefficients between merchantable board feet per acre and BA, H, and $BA \cdot H$ were 0.74, 0.85 and 0.87 respectively.

The recently developed quick-cruising methods based on prism or relascope, which give accurate field estimates of basal area, may be secured so cheaply that photo-mensurational techniques will encounter strong competition. The advocate of intensive use of photo-mensurational techniques must be able to demonstrate either more accurate or cheaper methods of measurement to make their use attractive

THE INDIVIDUAL TREE APPROACH

Determination of stand volumes based upon the estimation of volumes of individual trees was tried at an early stage in this investigation. The relationships between tree diameter at breast height (d.b.h.) and ground estimates of average crown diameter were assessed. Correlation coefficients based upon more than 100 trees of each species were 0.69 for douglas fir, 0.72 for hemlock, and 0.46 for cedar. Detailed analysis of the Douglas fir data showed important effects of crown class, tree height, and length of live crown on relationships between d.b.h. and crown width. In another sample of 179 Douglas fir trees, the correlation coefficient between d.b.h. and average crown width was 0.74. Replacement of "average" with "maximum" crown width of these same trees decreased "r" to 0.69. The d.b.h./crown-width relationships varied with density, average diameter, and site quality.

Because of the variations mentioned and the large number of measurements required to relate individual tree-volumes to stand volumes per acre, this approach was dropped.

DIRECT ESTIMATION OF STAND VOLUME PER ACRE

Three variables related to stand volume may be assessed directly on aerial photographs. These are stand height, average crown diameter, and stand density as expressed by a number of trees or per cent crown closure. Effective use of any of these measures requires adequate definition of sampling procedures and of the portion of the stand to be sampled.

If suitable photo-volume tables are available or can be developed, and if these are adjusted for the operator and tech-

niques involved, stand volumes may be estimated directly from aerial photographs. Although photo-volume tables are useful in typing and in reconnaissance cruises, best results in intensive cruising will come from estimates localized for each important type or stand under investigation. If a reasonably good photo-volume table is available, the interpreter saves the work involved in determining the equation relating stand volume to measurable factors. When a volume equation or table is available, the statistical technique of double sampling with regression should be used to construct what is in reality a local volume table for each important stand. The amount of calculation involved and the difficulties of locating the photo plots in the field may limit the application of the double-sampling technique.

Even with considerable experience, operators were unable to secure a high degree of correlation between volumes per acre and the variables measurable on aerial photographs of the study area. For one group of 15 one-fifth-acre plots, the multiple correlation coefficient of volume with height, crown width, and crown closure was only 0.65. For another group of 36 plots, the multiple correlation coefficient, based on $Y=0.28H+1.95CW+0.29CC-1.17$, was 0.50. Both of these coefficients were statistically significant but discouragingly small.

One operator secured correlation coefficients among volume and height, crown width, and crown closure of 0.76, 0.67, and 0.59 respectively. These combined by chance to give a multiple correlation coefficient of 0.95 but the actual data were unrealistically high, not useful for further interpretation. Another operator secured a multiple correlation coefficient of 0.79 for the same plots. His work could be applied further because his results were consistent with the data.

Although stand height was the variable most closely associated with volume, in all cases the additional contributions of average crown diameter and crown closure were both statistically significant and important.

Techniques Used and Possibilities of Improvement

AIDS AND EQUIPMENT USED

In comparison with many other methods and types of equipment for height measurement, the Abrams HF2 height-finder and Abrams CB1 2-power lens stereoscope were found to be most accurate and effective. The dot scale of the Michigan photo-interpreter's aid was best for measurement of crown widths in spite of inaccurate drafting of the dot series. The Michigan crown-closure scale was used in estimation of stand density.

Problems of measuring heights include the difficulties of securing good estimates of the ground level in dense stands and of determining the tops of tall trees with long-live crowns. Crown widths of such trees are also hard to measure and all measurements are difficult in dense stands. Since estimates of crown closure are subjective measurement errors are difficult to control.

All transparent photo-interpretation aids or equipment must be clean and free of scratches or blemishes. Light should be bright and preferably capable of adjustment in intensity. Photographs should be secured tightly with weights or drafting tape to a solid flat surface for study. Best results were obtained by using a combination of direct and indirect lighting on a light table. None of the devices available for increasing the overlap that can be measured with a height finder was found to be suitable. In this regard a system of mirrors permitting use of a lens stereoscope without overlap of photographs, developed by Professor Chittenden of the University of Washington, deserves further study.

ABILITY OF INTERPRETERS

A problem that is common to all measurements made on aerial photographs is the wide variation encountered within and between the work of individual interpreters. Estimates of the height of the same tree may vary widely from day to day and, indeed, from reading to reading. Experience, training, and systematization of procedures can reduce this variation but it remains discouragingly high for many people. Variation in itself is not necessarily a great problem so long as the estimates quickly approach the true mean, but the wider the variation in individual estimates the greater the number of readings required to secure a required level of confidence in the mean. The need for and advantages of practice are illustrated by the following example.

With 15 trees averaging 123 feet and ranging from 93 to 206 feet in height, one

operator secured an average estimate within 4.7 feet of the mean after 15 hours practice with the height finder. After 25 hours' practice, he was within 0.9 feet of the true mean height of the same trees. Another operator improved his measurements from an average error of −22.2 feet in the first run to −6.5 feet in the second series of measurements of the same trees. It was possible to show similar improvement in accuracy of estimate of crown widths. Within most stands it is possible to secure data that facilitate checks of height and crown width, but accurate checking of crown closure estimates is difficult.

In this study some crown closure estimates could be controlled by reference to ground maps of tree crowns. The estimate of crown cover on each plot was based on 25 transects each 2 chains long, on which the portion covered by crowns was measured from the map. The percentage of crown cover averaged 69.6 per cent on 8 plots. Subjective estimates on these plots, using a crown closure scale, averaged 75 per cent. Percentage crown cover on the strips taken to represent each plot had an average range of ±22 per cent, which indicates the highly variable stand conditions within these plots.

SCALE AND FOCAL LENGTH

Extensive comparisons were made of photographs taken at scales ranging from 300 to 2,600 feet per inch with cameras of $3\frac{1}{4}$-, 12-, and 20-inch focal lengths. The photographs at a scale of 1,000 feet per inch taken with a 12-inch focal-length camera were best for measurement of stand height, crown width, and crown closure. The major disadvantage of larger-scale photographs seemed to be associated with difficulties of holding adequate stereoscopic views of their very large images during measurement. This problem is similar to that encountered with the great exaggeration in parallax differences that is characteristic of short focal-length cameras. An important limitation to use of large-scale photography is caused by the relatively small area actually covered by any one photograph. Although individual trees and even branches may be clearly visible, the excessive displacement makes measurements difficult on all but a small portion around the center of each photograph. Tree tips and ground level can be distinguished quite easily near the center of each large-scale photograph. Considering cost and accuracy, photographs taken at a scale of 20 chains per inch with a camera having a 12-inch focal length would appear to be best for purposes of interpretation.

QUALITY OF PHOTOGRAPHS

For best results, great care is required in calibrating and mounting the camera. Photographs should be developed and printed carefully to minimize extreme variations in tone and to provide the sharpest possible image for stereoscopic study. A glossy finish seems to be best. So far no direct comparisons have been made among enlargements, contact prints, and positive transparencies, although these would be of considerable interest.

INHERENT LIMITATIONS

SPECIES IDENTIFICATION

Two separate approaches are being tried to improve the accuracy of species identification. The first is based upon the development of keys utilizing characteristic features of the images presented by various species in aerial photographs, and upon knowledge of the ecological factors influencing the situations where such species are usually found. The second approach is based upon the possible variations in light-reflecting ability of individual species, as determined by study of samples with a Beckman spectrophotometer. So far it has not been possible to determine consistent differences between stereoscopic views of Douglas fir and hemlock trees within these stands. Western red cedar, silver fir, and white pine trees may be distinguished from Douglas fir and hemlock in most cases.

At the present time all that can be offered is a subjective estimate of percentage composition by species from study of photographs or by extrapolation from information obtained on the ground during sampling within each type.

IDENTIFICATION OF SITE QUALITY

There may be some possibility of using the ratio of crown width to stand height in assessment of site quality.

Within all plots studied, the correlation between elevation and site index was very low. Within one 40-acre block, however, it was possible to sort plots into groups based upon topographic positions of ridge, mid-

slope, and valley. The two valley plots had an average site index of 153 feet at 100 years for Douglas fir. Ten mid-slope plots averaged 144 feet and two ridge plots averaged 136 feet in site index.

QUALITY AND DEFECT

The photo-interpreter must rely on field data to assess quality and defect. Such information should be collected on any plots established under a double-sampling plan.

Conclusions

As in all uses of aerial photographs, the advantages of photo-mensurational techniques depend upon the extent to which field observations may be replaced by the study of air photographs. If the intensity of the ground survey is to be high, and details of species, quality, defect, and site are required, the principal uses of aerial photographs would be in typing, mapping, and the control of inventory. There also could be little advantage to intensive application of photomensurational techniques in stands that are small in area and easily accessible. This would be especially true if high correlations between basal area and volume favored application of "quick-cruising" methods.

If the basic field sample is a cluster of plots that requires several man-days for establishment and subsequent analysis, important savings can be effected by a combination of field- and photo-sampling.

Photo-volume tables would have many possibilities of application both in reconnaissance and in inventories where stand maps are not required. Detailed photo-mensurational studies should be helpful wherever estimates must be secured quickly for a large area and in situations where ground-sampling intensities are to be light for management reasons or because of difficult access.

The success of attempts to supplement field measurements will depend on the accuracy of photo-volume tables used, the quality of photographs, and above all upon the training and experience of the photo interpreter.

An Improved Technique of Forest Type Transfer *

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UNTIL recently, the two most widely used methods of Forest Type Transfer were:

(a) Visual transfer from photo to map using the stereo-instrument.
(b) Direct transfer from photo to map using the Kail plotter.

In both cases the photos would normally have been interpreted by an experienced forester and in method (a) he would likely have carried out the type transfer to map himself, using the stereo-instrument.

Since it is unlikely that a qualified forester is an experienced stereo-operator, much expense and time are lost in releasing a stereo-instrument to such forestry representative and, of course, periodic services of a photogrammetrist to orient and scale the stereo model, etc. The repetitious glancing from photo to map/model is probably the most time-consuming factor of all.

The Kail plotter method (b) mentioned is doubtless more familiar in the industry and indeed, it will probably remain a permanent method of transfer in field locations. However, the time-consuming necessity of having to plot on the original base map about four picture points per 12-inch overlapping pair of photos, and the difficulty of plotting type lines by radial-line intersections, are doubtless well appreciated. The accuracy of placement and configuration of types can provide only a close approximation of timber volumes, etc.

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