A COMPARISON OF SOME 12-INCH AND 6-INCH FOCAL LENGTH PHOTOGRAPHS FOR PHOTO MENSURATION AND FOREST TYPING

by

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ABSTRACT

Photogrammetry has become increasingly important in the practice of forestry. Recently, the trend has been toward the development of photo-mensurational techniques for direct estimation of timber resources. The purpose of the present study was to assess the possibility of applying aerial stand-volume multiple-regression equations for the application of photo-mensurational techniques on several kinds of air photos.

Field data were collected from sample plots located in the U.B.C. Research Forest at Haney as well as from the forest on the campus of the University of British Columbia, in Vancouver.

Modifications in technique for the determination of tree height, crown width and crown closure were developed by the writer and are described in this study.

Multiple linear-regression equations were used for the analysis of data. Application of the Electronic Computer Alwac III-E to solve all the multiple linear-regression equations is described briefly.

Ease of typing was evaluated subjectively.

The present study has indicated:

(1) Using a spherical densiometer, a ground estimate of crown closure in per cent resulted in an over-estimate, as compared with the photo-estimate.

(2) Tree count could not be used effectively as an independent variable in the construction of the photo-volume equation.

(3) Best results were secured when photographs were taken with a 12-inch focal length and a flying height of 15,600 feet above sea level.

(4) For the construction of photo-volume tables, height, crown width and crown closure should be used as independent variables, especially when more than one interpreter is involved.

(5) No significant differences were found among photographic papers or finishes used for the determination of photo volume.

(6) Photography with a Representative Fraction (RF) of 1:15,840 should be satisfactory for forest typing.

(7) The greatest variation was among photo-interpreters.

(8) Photo-interpretation could be improved by the standardization of photo-interpretation procedures.

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A COMPARISON OF SOME 12-INCH AND 6-INCH FOCAL LENGTH PHOTOGRAPHS FOR PHOTO MENSURATION AND FOREST TYPING

INTRODUCTION

Aerial photographs give the forester a bird's-eye view of the timberland in which he is interested. More and more foresters have come to appreciate the application of aerial photographs to a number of problems in forestry practice, the greatest advantages being the saving of time and money.

In past years, successful efforts have been made to use aerial photographs in connection with mapping and cruising. However, aerial photographs have been applied mainly as an aid rather than as an essential tool. In the present day, it has become possible to secure aerial photographs of excellent quality, and to obtain greatly improved instruments and modern machines for the interpretation of aerial photographs. These make possible the use of photo-mensurational techniques for direct estimation of timber volume, for the construction of photo-volume tables, and for the reliable classification of forest types.

In this study, pertinent literature on photo interpretation is reviewed.

Field data were collected mainly from sample plots located in the U.B.C. Research Forest at Haney. Some field data were collected also from the forest on the campus of the University of British Columbia in Vancouver for comparison with those of the Research Forest.

In addition to the usual method for determination of tree height, crown width, and crown closure, modifications in technique were developed by the writer and are described in this study. Further tests of the accuracy of these new techniques will be carried out in a separate study.

Operators involved in the current study are described because their backgrounds influenced their photo interpretation.

Five sets of photographs with representative fractions (RF) ranging from 1:15,600 to 1:31,200 were used. These photographs were taken by Photographic Survey Corp. Ltd., Vancouver. Another two sets of photographs, with RF of 1:4,722 and 1:9,360, were used in addition for the study of forest typing. These large-scale photographs were taken in July, 1954, by Aero Surveys Ltd. of Vancouver.

Four kinds of photographic paper or finishes, i.e., positive transparency, Gevaert paper, and semi-matte and glossy finishes, were used to determine if significant differences in the estimation of photomeasurements existed among them.

Multiple linear-regression equations were used for the analysis of data, and were derived for each set of photo measurements and ground volume. Then the sum of squares removed in the multiple linear regression by each of the photo measurements, as well as multiple correlation coefficients, were calculated as a basis for comparison.

Use of the Electronic Computer Alwac III-E to solve all the multiple linear regression equations is described briefly, as well as the input and output procedures.

A number of tables are included showing the results of the analysis of data for the U.B.C. Research Forest and the Campus Forest, respectively.

Ease of typing was evaluated subjectively.

Summaries of data are given in the Appendix.

The specific objectives of the present study were:
(1) To determine which was the best combination for photo-mensurational work among 12-inch focal length photographs taken at a flying height of 15,600 feet above sea level and 6-inch focal-length photographs with flying heights of 15,600 and 8,400 feet above sea level.

(2) To determine which was most suitable for forest typing among 20-inch, 12-inch, and 6-inch focal-length photographs with flying heights ranging from 7,870 to 15,900 feet above sea level.

3. To determine the best variables to be used as independent variables for the construction of photo volume tables.

4. To assess the possibility of applying the aerial stand-volume multiple-regression equation within sampling units that were very small and that were in a rather uniform stand for the effective application of photo-mensurational techniques.

REVIEW OF THE LITERATURE

The interest of foresters in the application of aerial photography to forest mapping was first aroused by the successful use of airplane-mounted cameras during World War I. As early as 1919, Ellwood Wilson (Spurr 1954), a forester of the Laurentide Paper Company of Quebec, pioneered the use of aerial photographs in North American forestry. Early workers in the development of aerial techniques in Canada were Craig (1920), Hassel (1926), Jenkins (1927), Seely (1929) and Parsons (1930). Most of these people were concerned with the use of aircraft in forestry and their articles are mainly of historical interest.

While there was a gradual development of techniques and equipment for aerial photography following World War I, by far the greatest advances were made during World War II, when the finest possible equipment was demanded for aerial reconnaissance and photo interpretation and there was no lack of funds for developmental work. The result has been a greatly increased interest in the application of the new equipment and methods to other fields, including forestry, and a steadily increasing volume of literature on the subject.

The extensive literature on photo interpretation as related to forest photo-measurements has, for convenience, been divided into the following sections:

1. the influence of scale and focal length
2. measurement of tree height

3. measurement of visible crown-width
4. estimation of crown closure
5. correlations observed between volume and photo-measurable variables.
6. forest typing.

Influence of Scale and Focal Length

The scale of aerial photographs is generally stated in terms of the Representative Fraction and abbreviated to "RF". If a photograph is said to have an RF of 1:15,000, it is reproduced at such a scale that a given distance on the ground is 15,000 times greater than on the photograph. Scale is not constant within any given photograph due to variation in ground elevation. It is controlled by the focal length of the camera and the height of the plane above the area being photographed. The greater the height of the aircraft, the smaller will be the scale of the photographs. Few aerial photographs are taken at an elevation lower than 5,000 feet because the air is too rough for accurate, steady flying. Conversely, the taking of photographs above 20,000 feet above sea level will entail the use of more expensive, pressurized aircraft capable of maintaining this height.

The larger the scale adopted (or the smaller the RF), the greater will be the number of photographs required and the higher will be the material and processing costs.

Photo-interpretation is greatly influenced by photographic scale. Interpretation for certain purposes is limited by scale. Photographs of RF 1:31,680 have little forestry value other than for the delineation of classes of forested and non-forested lands. On 1:24,000 photographs, relatively broad forest classification can be satisfactorily made and crown closure can be separated into broad classes.

There is very little difference between scales of RF 1:20,000 and 1:24,000. An RF 1:20,000 is the standard scale of the U.S. Department of Agriculture but the consensus of opinion in the literature indicates that most foresters feel that it is too small for forestry purposes, an RF of 1:15,840 being widely accepted as a suitable scale for forestry practice. With the latter scale, fairly accurate measurements can be obtained from photographs for both forest mapping and photo interpretation. It is a standard scale in Canada for forestry purposes.

On scales of RF 1:10,000 and smaller, detailed characteristics of individual trees, species composition, and various photo measurements can be accurately determined, but the cost of photographs will be much higher.

In general, for the preparation of base maps it is believed (Spurr 1948) that a scale of RF 1:31,680 is economical and adequate for ordinary mapping. Delineation of small forest types and accurate estimates of tree heights and volume require much larger scales. Industrial foresters seem prepared to accept the scale of RF 1:15,840 as a compromise. Non-industrial foresters frequently require larger scales for specific purposes, and at least an RF of 1:15,840 for general forestry work. These have been recommended by Seely (1935), Moir (1936), Spurr and Brown (1946), Wilson (1946) and Jensen and Colwell (1949). However, in 1954, Young (Wood 1954) stated that some companies in Maine are abandoning the almost universally used photo scale of RF 1:15,840 for much smaller scales and are using higher powered stereoscopes in order to save money spent on photographs.

Lenses of 6-, 8 1/2- and 12-inch focal length are frequently used for various scales. The focal length of the lens not only influences the photo scale, but also the stereoscopic image. The effect of using a short focal-length lens is to increase topographic displacement and apparent depth. Therefore, if photographs are to be taken for forestry use, the 6-inch focal-length lens should not be used except over relatively level country.

Measurement of Tree Height

In solving photo-mensurational problems, the relatively high correlation between average tree height as measured on aerial photographs and stand volume makes measurement of height important. The accuracy of tree-height measurement on aerial photographs depends mainly upon the scale of photography, focal length of the lens, time of photography, method of measurement, skill of the observer, and character of the forest being studied.

Photographic scale is equal to focal length divided by the flying height above ground. It is not always true that heights can be estimated more accurately from a larger scale photograph since the increased stereoscopic parallax at the larger scale makes difficult the simultaneous stereoscopic fusion of tree top and ground.

As early as 1935, Seely (1935) determined a method for measuring tree height through measurement of image or shadow on single vertical aerial photographs. Andrews (1936) developed a simple method for measuring tree heights from aerial photographs. This method is based on measurements with a micrometer of the difference in parallax between the tip and the base of a tree from stereoscopic study of vertical aerial photographs. His average error on 1:9,000 photographs was six feet on 56 trees of average height of 88 feet.

Spurr, (1945) regarding tests at the Harvard Forest, stated that an observer can measure tree heights with the parallax wedge on photographs of a scale of RF 1:12,000 with an average error of less than three feet. Spurr (1948) found that experienced interpreters can consistently measure tree heights with an error of less than five feet. Therefore he reported that the average interpreter should be able to classify trees into five-foot height classes when using 1:12,000 photographs.

Garver and Moessner (1949) found that using aerial photos at a scale of RF 1:20,000 and a U.S. Forest Service parallax wedge, a skilled photo-interpreter can, in two cases out of three, measure tree heights with an error of less than ± 10 feet. At the same time, Nash (1949) tested 1:7200 photography for use in measuring tree heights by the shadow method, the average error of estimate being ± 2.2 feet. Moessner (1950) again indicated that it is possible on recent 1:20,000 photos of good quality to measure tree heights by an inexpensive parallax wedge with an average error of less than 6 feet in comparison with Abney level readings taken in the field. Getchell and Young (1953) found that the greatest single error in the measurement of tree height was 11 feet when using 1:15,840 photographs.

They also indicated that a period of between 12 and 18 hours was needed for experienced photo-interpreters to become proficient in the use of wedge-type parallax ladders and floating-dot attachments to lens stereoscopes for measuring tree heights on aerial photographs.

In the same year, Losee (1953) used both 1:1,200 and 1:7,200 photography of eastern Canadian forests to determine how much the use of large scale photographs would influence the precision of tree height measurements. The average error of height measurement on the 1:7,200 photographs was 0.6 ± 2.1 feet, and for the 1:1,200, 2.1 ± 0.5 feet, both at 0.95 probability, and determined by means of a parallax bar. Ker (1953), in a paper on the estimation of tree heights from aerial photographs, found that, although an appreciable error appeared to exist, a reasonable degree of consistency was attained in the measurement of tree heights from photographs with a scale approximately RF 1:15,840.

Worley and Landis (1954), studying the accuracy of height measurements with parallax instruments on 1:12,000 photographs, found that systematic errors are larger for the parallax bar than for the parallax wedge, and accidental errors were found to be from 8 to 10 feet. Allison (1956), working with various aerial photographs, adjusted all photo-measured heights for the mean differences between actual height and photo-measured heights, and presented a table of expected errors in height measurement. He concluded that tree heights appear less and individual height determinations become less precise with increased flying height and/or shorter focal length and/or greater degree of enlargement, and that there is no significant difference between various qualities of aerial photographs in the accuracy of tree-height measurements.

Pope (1957), studying the effect of photo scale on the accuracy of forestry measurements, found that accuracy of height measurement varied considerably among interpreters, but did not differ significantly with photo scale. Smith (1957) reported that with 15 trees averaging 123 feet, 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. Collins (1957), checking the accuracy of tree height taken from aerial photographs, found that the standard error of individual height estimates for 40 trees was ± 6.1 feet for dominant and codominant trees and ± 5.1 feet for dominants only. He concluded that estimates of maximum height for site classification can be made with excellent reliability from aerial photographs.

In order to save time in measuring tree height with a parallax wedge, Moessner and Rogers (1957) developed a table and a graph in which parallax factor (height of object in feet per .001 inch -- usually expressed as parallax difference or dp) was determined for flying heights in feet for various base lengths. When elevations varied from -543 to +636 feet from mean datum, the standard error of estimate for trees of all heights was ± 10.6 feet without adjustment for elevation. This was reduced to from 3 to 4 feet when adjustments were made for elevation differences. They indicated that increasing flying height or photo overlap tended to reduce the differences between graphs or tables and formula computations. They also mentioned that adjustment of the wedge was simpler and faster than the operation of the micrometer wheel used in floating-dot methods of measurement.

Recently, Johnson (1958b), working on the effect of photographic scale at RF's of 1:20,000, 1:15,000, 1:10,000 and 1:5,000, found that errors were not associated with photographic scale, but with the individual operators.

Later in 1958, Rogers (1958) reported for Working Group 4, Commission VII, of the International Society of Photogrammetry, that the average height for dominant trees in stands of hardwoods can be measured within 10 per cent two times out of three. Individual hardwood tree heights can be measured with a standard error of estimate of nine feet using 1:12,000 photographs.

In December of 1958, Bernstein (1958) concluded that there are definite differences among photo interpreters, but magnification does not seem to be a promising way to improve height measurements.

In the articles referred to above, the results were not uniform but varied from interpreter to interpreter as well as from photograph to photograph. However, the larger scales tended to give consistently better results for the determination of tree heights from aerial photographs. With good quality photographs and visible bases of trees, an experienced interpreter should be able to classify tree heights into 5-foot classes on photos of RF 1:10,000 and smaller, into 10-foot classes on photos of RF 1:12,000 and 1:15,840, and into 15-foot classes on photos of RF 1:20,000. In discussing errors in the estimation of tree heights, it would be better to express them as a percentage of the actual height rather than in feet alone. An error of 10 feet is only 5% in the estimation of the height of a 200-foot tree, 10% in the measurement of a 100-foot tree.

Measurement of Crown Width

On large-scale aerial photographs, crown width probably can be estimated more accurately than if measured on the ground, since one can see more clearly the upper portion of tree crown on the aerial photograph. The accuracy of crown-width estimation will depend largely upon the scale of the photograph, the tree species and the pictorial sharpness of the print. Crown widths are commonly measured on aerial photographs with either a crown wedge (Wilson 1948) or a dot wedge (Jensen 1948).

In early 1946, Wilson (1946a) stated that crown widths could not be measured closer than plus or minus five feet on 1:20,000 photographs. He concluded that crown-width classes should not be less than 10 feet using this scale of photograph. Spurr (1948) found that experienced interpreters could consistently measure crown widths with an error of less than 3 feet on 1:12,000 aerial photographs. Garver and Moessner (1949) reported that interpreters could be expected to classify crown widths consistently in 5-foot classes on 1:20,000 photographs using the dot wedge. Miner (1951), in his study of stem-crown-diameter relations in southern pine, mentioned that crown width classes of three and five feet can be used for classification of crown widths on 1:15,840 and 1:20,000 photographs, respectively. Losee (1953) indicated that crown widths were measured on 1:1,200 photos with an average error of -0.09 ± 0.33 feet at 0.95 probability, and could not be satisfactorily measured on the 1:7,200 photos in eastern Canadian forests. In 1954, in a test of the accuracy of measurements of crown diameter for for 1:12,000 photographs, Worley and Meyer (1955) found that the standard error of estimate of individual crown-diameter measurements, made with either the shadow wedge or with a dot transparency, was between 3 and 4 feet. Dilworth (1956) applied visible crown diameter/diameter at breast height relationships by graphical and multiple correlation equation methods. He found that when visible crown diameters were used to estimate diameter at breast height, the standard-error of estimate of d.b.h. (diameter at breast height) ranged from 1.17 to 2.53 inches. The simple correlation coefficients varied from 0.900 to 0.996. He further mentioned that this relationship was influenced more or less by tree species, geographical location, density of stocking, tree height, and site quality. Rogers (1958) reported that crown widths were estimated consistently with a standard error 3.5 to 4.0 feet at scales of 1:10,000 and 1:15,000 photographs. At larger scales of RF 1:5,000 and 1:7,000, standard errors of estimate ranged from 1.8 to 1.9 feet. On a very large scale of RF 1:1,200, the standard error of estimate was only 0.54 feet.

In general, crown widths could be consistently classified to within 2-foot classes at scales less than RF 1:12,000, 3-foot classes at 1:15,840, and 5-foot classes at 1:20,000. Obviously, crown width measurements are more accurate in open-grown stands, whereas in dense stands, measurements are usually in terms of average dominant trees.

Measurement of Stand Density

Crown closure is the most commonly used estimate of stand density from aerial photographs. It is the proportion of the forest canopy occupied by tree crowns, usually expressed to the nearest 5 per cent. The accuracy of crown-closure estimate is dependent upon the ability of the observer to see holes in the crown canopy rather than upon the observation of individual tree detail.

As early as 1934, Andrews (1934) suggested that it was possible to planimeter the crown openings on aerial photographs to get the percentage of crown closure, but this method is too tedious for general application.

Crown closure can be estimated ocularly from aerial photographs studied under the stereoscope with the aid of a crown-density scale (Moessner 1947).

Spurr and Brown (1946) indicated that crown closures could be estimated to the nearest 10 per cent on photos ranging in RF from 1:10,000 to 1:18,000. A year later, Moessner (1947) also reported that estimates of crown closure can be made consistently within 10 per cent. In 1954, Worley and Meyer (1955) found that individual observers have a tendency to either over-estimate or under-estimate the relative crown cover of a stand using either dot counts or grid comparisons. Recently, Rogers (1958) reported that stand volumes of hardwood forests can be estimated within 10 per cent with photos of RF 1:12,000 and 1:20,000. He mentioned that, at RF 1:1,2000, a standard error of estimate of 8.7 per cent had been obtained.

Tree counts, as a measure of density, can seldom be made accurately from photographs, and counting all trees on a single plot is tedious. This measure of density is seldom used, although individual tree counts may be much more reliable where large-scale photographs ranging from RF 1:1,000 to 1:5,000 are available. Rogers (1958) reported that total tree counts have not been very successful. Even on a scale of RF 1:1,200, one can seldom count over 50 per cent of the total number of trees, while at scales of RF 1:15,000 and 1:20,000, only 30 per cent of the total number of trees can be counted.

In the literature reviewed, little has been said about the actual techniques of measuring tree heights and crown widths, and estimating crown closure. These will be discussed later.

Correlations Between Volume and Photo-measurable Variables

Tree and stand volume may be directly correlated with diameter at breast height, total height, site quality as expressed by average height of dominant and codominant trees, basal area, age, and density index.

Diameter at breast height has been found to be highly correlated with crown width, which is measurable from aerial photographs. Stand volumes can be determined from aerial photographs through correlation with three variables, viz., tree height, crown width, and crown closure, if these can be evaluated directly under the stereoscope with reasonable accuracy.

Since the introduction of aerial photographs to forestry in 1919 (Spurr 1954), foresters have realized that volumes of tree and stand can be estimated directly from measurements made on aerial photographs, but practical application has been slow. The first photo-volume tables in North America were constructed by Spurr in 1948 (Dilworth 1956). He found that both crown width and total height showed a close correlation with tree volume, the correlation coefficient being 0.83. For an empirical stand-volume relationship for white pine, based on total height alone, the correlation coefficient was 0.937. Variations between photo-estimates and ground volume were tested. The average error on a total of ten stands was only +8.6 per cent. In the same year, Nash (1948b), using d.b.h. converted from crown width and total height applied to

Seely's formula:-

$$\frac{Kh}{d^2} = E$$

where h = total height of tree
K = crown width
d = d.b.h.
E = a coefficient,

constructed an aerial tree-volume table for white pine stands. In 1949, using data from 18 0.2-acre plots, Pope (1950) drew a curve of per-acre volumes over average height of dominant and codominant trees. All plot volumes were then adjusted to a crown closure of 85 per cent by assuming volume to be directly proportional to crown closure. A test of the stand photo-volume table showed a standard error of estimate of $\pm$ 5.1 per cent for all plot and $\pm$ 21.8 per cent for single observations. Another approach was to convert yield tables for Douglas-fir developed by McArdle, Meyer and Bruce (1949) for cubic volume from volume over age to volume over stand height. Then volume per acre was plotted over average stand height by crown closure classes. The standard errors of estimate were $\pm$ 4.8 per cent and $\pm$ 20.4 per cent for the total number of plots and for single observations respectively. Dilworth (1956) concluded from these preliminary tests by Pope that; (a) photo-volume tables have considerable potential value for use in supplementing ground plots. (b) variables used in the photo-volume tables can be measured accurately enough for use,

(c) stand photo-volume tables are somewhat more satisfactory than tree photo-volume tables, (d) a photo-volume table must be prepared from data that represent trees and stands that are similar as to site, age, species and density to the trees or stands that are to be estimated. Moessner, Brunson, and Jensen (1951) constructed a set of photo-volume tables for hardwood stands in Kentucky. Volumes per acre were converted from field data taken on 0.2- and 0.1- acre concentric circular plots. Average total height of dominant stand, average crown widths of dominant trees, and crown closure in per cent were made on one-acre plots. The photo-volume tables were constructed by the alinement-chart method of Bruce and Reineke (1931). A variation of from -6.0 to -10.3 per cent was found between photo and ground plot volumes. Moessner and Jensen (1951) again prepared a similar photo-volume table from RF 1:20,000 photos for Allamakee County, Iowa, the difference in the mean per-acre volume between photo and ground estimates being -6.2 per cent and -1.8 per cent for two 40-acre areas. Losee (1953) constructed a stand aerial-volume table based on crown width, total height and crown closure correlated with volume per acre. The error between photograph and field estimates was ± 7.7 per cent and ± 4.3 per cent for RF 1:1,200 and 1:7,200 photographs respectively. At the same time, Ferree (1953) prepared his photo-volume tables based only on mean visible crown width for 1:16,000 photographs of normally stocked stands. He found that the tree-count method was not satisfactory. An accuracy of

$\pm$ 30 per cent on volume estimates of individual plots was found.

Gingrich and Meyer (1955) developed a new approach for the construction of aerial photo-volume table using RF 1:12,000 photographs for upland oak stands located in Centre County, Pennsylvania. Tree counts on the photographs were found to be poorly correlated with ground counts. Stand volumes obtained from field data were correlated with various photo measurements. They found that the partial correlation coefficient between crown width and stand volume, after eliminating the effect of both stand height and crown closure, was not significant. They tested and concluded that an equation, expressed as stand volume based on stand height and crown closure per cent, was the best solution for the construction of photo-volume tables. Multiple-correlation coefficients were found to be 0.85 and 0.87 for equations relating to cubic-foot volume in trees 5 inches and larger and 7 inches and larger respectively, solved by means of the least-squares solution. Allison (1955) constructed a photo-volume table by a multiple linear correlation analysis of ground volume obtained from field plots and photo measurements of tree heights, crown widths, and crown closure per cent on the same plots. The equation was as follows:

$$\text{Volume, cubic feet} = 58.06 \text{ (tree height, in feet)} \pm 33.46 \text{ (crown width, in feet)} + 40.57 \text{ (crown closure, per cent)} - 2653.$$

A test of a 2,600-acre area showed that total gross cubic volume was 13.1 to 14.8 million cubic feet from ground samples and 13.9

to 14.9 million cubic feet from aerial photo samples. The standard error of the difference was ± 378 cubic feet, and the difference of means was 164 cubic feet per acre. Another test of a 4,630-acre area showed that total gross cubic volume was 24.5 to 27.3 million cubic feet for ground estimates, and 22.9 to 24.9 million cubic feet for aerial samples. The standard error of the difference was 374 cubic feet, and the difference of means was 429 cubic feet per acre. Thus, estimates made from aerial photographs do not differ significantly from the total gross cubic-foot-volume estimates obtained from ground cruises. Further, the completion of the aerial-photo cruise required only 7.5 per cent of the time and 12 per cent of the cost of the ground cruise. In a study on the estimation of the growing stock from aerial photographs, Nyyssonen (1955) constructed an aerial-volume table for Scots pine in southern Finland by the curve-fitting method. He found that the standard error of estimate of volume determination by crown closure only was approximately ± 35 per cent. When mean height was taken into account, the standard error of estimate became ± 29 per cent.

After finding a strong correlation between diameter at breast height and crown width, and between diameter at breast height and the variables of crown width and total height, Dilworth (1956) developed a suitable equation for estimating d.b.h. (Y) from crown width (X_1) and total height (X_2) as follows:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_1X_2$$

where a, b_1, b_2 and b_3 are coefficients. Then, he constructed both local and standard photo-volume tables based on crown width and tree height by means of a graphical method. In a test of precision of the local photo-volume tables, he found an aggregate difference of -1.4 per cent and a standard error of estimate of 26.7 per cent. Another similar test of the standard photo-volume tables gave aggregate differences varying between +0.41 and +0.78 per cent and standard error of estimate ranging between 6.9 and 13.5 per cent. Moessner (1957) prepared some preliminary aerial-volume tables for coniferous stands in the Rocky Mountains. These composite tables were constructed by the alignment-chart method for solving problems in multiple curvilinear correlation described by Bruce and Reineke (1931). Total heights were measured on 1:20,000 photographs with a standard error of estimate of less than ± 10 feet. Other measurements were of comparable precision. Tests of the tables showed that photo estimates made with 10 to 20 plots did not vary significantly from those made in the field. Other tests indicated that correlation between field and photo volumes usually exceeded 90 per cent, when plots were stratified in 4- or 5-plot groups.

Smith (1957) stated that even with considerable experience, some operators were unable to secure a high degree of correlation between volumes per acre and the variables measurable on aerial photographs. For one group of 15 0.2-acre plots, the multiple correlation coefficient of volume with tree height, crown width, and crown closure was only 0.65. For another group of 36 plots, the multiple correlation coefficient was 0.50. Both of these multiple correlation coefficients were statistically significant but discouragingly small. One operator secured correlation coefficients between volume and height, crown width, and crown closure, respectively, of 0.76, 0.67, and 0.59. The multiple correlation coefficient was 0.95, but the photo estimates were unrealistically high. Another operator secured a multiple correlation coefficient of 0.79 for the same plots. Stand height proved to be the variable most closely associated with volume, but the additional contributions of average crown width and crown closure were both statistically significant and important.

Morris (1957) set up a new approach for photo volume table construction. By the least-squares method, he correlated ground volume as the dependent variable with stand density in per cent for each 20-year age class. Stand density in per cent was estimated by comparing stand density on photographs with density stereograms. Age classes of a stand were determined by studying the pictorial features, such as tree heights, crown sizes, and crown shape. Using 1:15,840 photographs, he found that standard error of estimate in volume was 420 cunits*

* A cunit is a unit of volume measure containing 100 cubic feet.

or 7.7 per cent on a tract of timber with 5,470 cunits.

Allison and Breadon (1958), assuming a linear relationship between gross volume per acre and each of the two independent variables, tree height and stand density, prepared aerial photo volume equations for two Interior Forest Zones in British Columbia using 1:15,840 photographs. Each equation was constructed by a least-squares solution of the following equation:

$$\text{Volume, in cubic feet} = a + b_1\,(\text{stand height, in feet}) + b_2\,(\text{Crown closure, per cent})$$

where a, b_1 and b_2 are coefficients. Values of the correlation coefficients obtained follow:

Item	Mature Coniferous	Immature Coniferous	Lodgepole pine and deciduous species all ages
Zone 4			
-Multiple correlation coefficient	0.50	0.64	0.46
-Partial correlation coefficient(vol. on height)	0.46	0.64	0.46
-Number of double samples	165	44	37
Zone 6			
-Multiple correlation coefficient	0.28	0.51	0.66
-Partial correlation coefficient(vol. on height)	0.18	0.33	0.39
-Number of double samples	119	23	16

In the application of the photo-volume table, a double sampling should be made. This involves production of a local regression of photo volume on ground volume. Allison (1958) chose an area of 25,800 acres in Cochran Creek drainage, British Columbia, for a test of double sampling. After the local photo volume/ground volume regression was calculated, it was found the double sampling gave an estimate of volume per acre of 3,767 ± 714 cubic feet, whereas ground-estimated volume per acre was 3,603 ± 1,136 cubic feet. Allison further indicated that, based on ground sampling, the average gross volume per acre for the mature coniferous type was 31.6 per cent in error, whereas the error of the photo-volume estimate was only 19.0 per cent. He indicated that photo measurements of tree height contributed most to the multiple correlation with ground volume. Photo measures of crown width added practically nothing, with the result that crown width was not used. He also mentioned that he located twenty sample plots near Patricia Bay for testing interpreters. As a criterion of suitability, a minimum correlation coefficient of 0.80 was set, together with limits on the slope of line plotted to the data by least squares and a limit to the scatter about the line. He concluded that about 4 out of 25 interpreters were satisfactory. At the same time, Pope (1958) stated that the interpreter is not just a mechanical link in the process of interpretation. This process may be more of an art than a science.

It is clear that experienced photo-interpreters can do timber cruising directly from aerial photographs with a minimum of ground control at the normal standards of accuracy. It is obvious that the greatest advantages of photo cruising are the savings in time and money, and relative independence from weather hazards.

Forest typing

Stand mapping is an important link in the practice of forestry, since maps showing the status and condition of land provide essential records upon which forest management is based. As early as 1919 (Thelen 1919), aerial photography was being used as an aid in forest mapping. Since then it has been adopted by all countries in the world for this purpose.

Forest typing is the main concern in forest mapping. This may involve the determination of location of timber, area, volume, stand size, species composition, tree height, stand density, crown class, topographic site, and accessibility. In the early application of aerial photographs to forestry, Foster (1934) realized that, without supplementary ground work, aerial photographs can not be depended upon for forest typing.

Spurr and Brown (1946) indicated that forest species could not be positively identified unless the photo interpreter was familiar with the area being studied and had the opportunity of checking in the field. They further stated that intensive study on the ground is very helpful in the interpretation of any area, and knowledge of the ecological habits of the local species will help the interpreter to differentiate forest types.

Colwell (1948) stated that identification of individual species of vegetation on 1:10,000 photographs can only be done in special instances. By increasing the scale of photography to somewhat greater than RF 1:10,000, species of vegetation can be identified through the use of branching characteristics, textural differences in foliage, shape and size of crown, and other features. He found that the use of colour photography was only partially successful, since the problem of differentiating between tones of green on colour transparencies is the same as applied to tones of grey on black-and-white photography. Jensen and Colwell (1949) again mentioned the importance of checking on the ground when classification of all dominant species was made from aerial photographs. In the same year, Seely (1949) found that the use of large-scale photographs and field checks were of great assistance in the identification of species.

Hixon (1950) found that the various species could not be successfully identified on photographs with an RF of 1:20,000 taken over National Forests in the Douglas-fir subregion of southern Oregon. Losee (1951) indicated that, although the interpreter uses his knowledge of the species present in the area, their phenology and site preferences, as well as the tone present in the photograph, the difference in tone provides the final separation between spruce and larch under eastern Canadian conditions.

Moessner (1953) stated that classification of stands is generally on the basis of forest types, based upon species; forest site, based upon topography and soil conditions; and stand size, based upon crown width and height of trees. Since forest types, as well as stand size, stand quality, height and crown width of trees, and growth rate, are correlated with forest soil and topography, forest typing can be done well with careful stereoscopic study of photographs and a minimum of ground control.

Smith (1957) suggested that the accuracy of species identification can be improved by the development of keys utilizing characteristic features of the images presented by various species in aerial photographs, knowledge of the ecological factors influencing the situations where such species are usually found, and the possible variations in light-reflecting characteristics of individual species as determined by study of samples with a Beckman spectrophotometer. He reported that it was not possible to determine consistent differences between stereoscopic views of Douglas fir and western hemlock trees within these stands, but western red cedar, silver fir, and white pine trees may be distinguished from Douglas fir and western hemlock in most cases.

In a spectrophotometric analysis of foliage of some British Columbia conifers, Hindley and Smith (1957) found that wide variations in reflectance within a species and relatively small differences among species make it difficult to differentiate between species. They suggested that knowledge of typical range in size, shape, branching habit, and ecological characteristics of species or species groups would facilitate species identification.

Rogers (1958) reported that the identification of tree species in Indochina has not been successful on RF 1:40,000 photographs. It was believed that during the flowering season, identification of tree species on aerial photographs would be possible. In Sweden, tree species were correctly identified from 77 to 94 per cent of the time on RF 1:25,000 photographs. But identification of species was impossible on photographs of RF 1:15,000 to 1:20,000 in mixed forests in eastern United States, and only 37 percent were identified correctly at a scale of RF 1:1,200, and 25 per cent at a scale of RF 1:4,800, when panchromatic film was used. Rogers also mentioned that a key to photo interpretation for identification of hardwoods is being tested in Pennsylvania and Kentucky by the Northeastern Forest Experiment Station in Berea, Kentucky. The same station was assessing photos of RF 1:15,800, 1:5,000, and 1:1000 taken on panchromatic and infra-red films for species identification, and measurements of tree height, crown width, and stand density.

For best results in forest typing, one should combine powers of observation, judgement, and imagination to evaluate what is seen under the stereoscope on aerial photographs.

Furthermore, one should always keep in mind that the adopted scale will influence greatly the costs of obtaining any aerial photographs to cover one particular area. The cost of RF 1:15,800 photographs will be four times less than that of RF 1:7,800 and four times more than that of RF 1:31,200, whereas photographs with RF 1:7,800 will cost sixteen times as much as that of RF 1:31,200.

COLLECTION OF DATA

Collection of field data

A number of stand photo-volume tables has been constructed by using various methods (Pope 1950; Moessner 1951; Moessner, Brunson, and Jensen 1951; Losee 1953; Ferree 1953; Gingrich and Meyer 1955; Allison 1955; Dilworth 1956; Moessner 1957; Morris 1957; Allison and Breadon 1958), and stand photo-volume tables are somewhat more satisfactory than individual tree photo-volume tables (Dilworth 1956, Smith 1957). Hence the writer decided to use the stand approach to volume determination for this study.

Field data for this study were collected from sample plots located in the U.B.C. Research Forest at Haney, and in the Forest on the Campus of the University of British Columbia, at Vancouver.

The main portion of field data was collected by the writer and one assistant at the U.B.C. Research Forest, where the writer worked as a research assistant during the summer of 1958. The area studied is near the south-east corner of Loon Lake and north of Blaney Lake. It ranges in elevation from 1,140 to 1,320 feet above sea level. The terrain, in general, is moderately steep. The stands studied range in age from about 55 to 85 years, averaging approximately 70 years. The average site is about 140 feet at 100 years. Species present are Douglas fir, western hemlock, western red cedar, and silver fir. The species composition varied widely over the area.

Fifteen randomly located sample plots had been established for studying the response to a commercial thinning. The actual thinning was done in 1956. These stands are adjacent to roads and are relatively open after thinning. These plots are one by two chains in size with the long side of the plot running north and south. For each plot, all trees were tallied by species and d.b.h. taken to the nearest 0.1 inch with a diameter tape. The heights of dominant and codominant tree were measured to the nearest foot with a 100-foot chain and a Haga height-finder. Crown widths of dominant and codominant trees were measured to the nearest foot by the plumb-bob method (Nash 1948a). Average crown closure was determined from 18 estimates systematically located by dividing each one-by-two chain plot into 22-foot squares after allowing 11 foot margins on both sides. One estimate was taken at each corner of each of the 10 sub-plots. Crown closure per cent was estimated using a spherical densiometer (Lemmon, 1957). Total cubic-foot volume per acre for each plot was derived from U.B.C. Research Forest local tree-volume tables by classes of maximum height and d.b.h. Data for the 15 sample plots after thinning follow:

Table 1

Summary of ground data for 15 0.2-acre plots after thinning

Plot No	Site index feet	D.b.h. in ft.		Height in ft. of dom. and codom. trees.		Crown width in ft. of dom & codom trees.		Crown closure %	
		Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.
1	135	5.5-21.7	13.5	110-127	119	18-29	23	75-90	83
2	156	5.7-24.9	12.7	108-144	128	16-29	18	75-92	84
3	156	5.8-33.7	16.6	114-171	138	19-34	24	58-83	72
4	150	5.8-32.3	13.1	88-148	120	16-30	22	75-95	84
5	138	5.5-22.3	12.8	94-137	118	18-28	22	62-90	83
6	135	4.1-20.6	11.5	76-120	104	12-24	19	67-92	83
7	140	6.0-24.7	12.1	82-138	117	16-29	21	67-90	81
8	146	6.3-31.5	13.9	108-170	134	20-35	27	83-95	88
9	146	5.6-40.7	13.7	104-158	126	28-46	32	58-92	81
10	148	6.2-33.4	14.8	96-149	120	24-42	29	71-87	81
11	145	5.4-25.9	10.7	88-136	93	16-31	20	83-92	88
12	140	5.9-20.2	13.9	90-126	104	17-28	22	42-83	64
13	154	6.2-26.4	12.7	101-149	120	17-25	21	77-96	86
14	132	5.9-20.0	10.7	86-123	100	15-25	19	75-90	85
15	140	11.8-36.9	20.8	112-150	133	18-36	24	57-87	76

No. of trees on plot	No. of trees per acre	Volume cu. ft.		
		Volume per tree cu.ft.	Volume per plot	Volume per acre
29	145	40	1148	5741
44	220	48	2124	10619
22	110	89	1968	9840
32	160	48	1543	7714
34	170	43	1451	7253
31	155	32	989	4947
31	155	42	1296	6480
41	205	62	2538	12690
27	135	65	1752	8759
33	165	66	2163	10816
64	320	31	2008	10038
13	65	53	684	3422
37	185	43	1608	8041
45	225	28	1255	6277
15	75	148	2076	10382

Field data for the Campus Forest sample plots in this study were collected by 11 students as part of the field work in Forestry 464, a senior photogrammetry course, each student working on his own ground plots. This forest is located on the southern edge of the University Campus south of the University Farm. The stands range in average age from 40 to 110 years, and in site index from 100 to 160 feet at 100 years. Total cubic-foot volume on individual 0.1-acre circular plots ranges from 200 to 2,420 cubic feet. Average tree height and crown width of dominant and codominant tree for each plot ranges from 60 to 150 feet and 12 to 32 feet, respectively. Average crown closure on each plot ranges from 20 to 100 per cent with an average for all plots of 75 per cent. Species found in the area are Douglas fir, western hemlock, western red cedar, with scattered alder and cherry trees. In general, the terrain is faily flat. Five groups of 0.1-acre plots, 84 in all, were selected at random. Plots in one group were located systematically on the ground as well as on photographs, studied under the stereoscope in the field. Two students, working as a team, took the measurements and carried out the estimations in the field. Heights of dominant and codominant trees were measured with a 100-foot chain and Abney level. Crown width of each tree was estimated by the plumb-bob method (Nash, 1948a). The average crown closure for each plot was also estimated ocularly. Individual diameters at breast height were measured with calipers, and local tree-volume tables in cubic feet were used to calculate total cubic-foot volume per acre.

Location of sample plots on photographs

After a study of ground conditions was complete, fifteen 0.2-acre plots were marked on one of the photographs in the field at the Research Forest with the aid of a pocket stereoscope. The southwest corner of each plot was pricked.

A total of 84 0.1-acre sample plots were located similarly in the Campus Forest.

Measurement of photo data

1. Methods for each kind of photo measurement

(a) General

All interpreters worked with the aid of both direct and indirect lighting on a split-top light table, except interpreters C, D, and G (see below - operator). An Abrams Heightfinder, model HF2, was used for height measurement. The U.B.C. photo-interpreter's aid was used in the determination of crown widths and crown closures. An Abrams C B I stereoscope was used throughout.

In order to avoid memory bias, no more than one set of photo-measurements of 15 0.2-acre plots were made within any three days. For tree heights, the parallax of the top and the base of each tree was measured and recorded. When the ground could not be seen clearly, care was taken to make the ground parallax reading on the same contour as the base of the tree. For the estimation of the average crown widths, the four tallest trees on each plot were located under the stereoscope, the size of each tree crown measured, and the reading recorded. The conversion of these data into average tree height and crown width in feet was carried out after measurements were made for that set of photographs. At the same time as tree heights and crown widths were measured, crown closure was recorded for each plot. Another safeguard adopted was that photo measurements for the first set of photographs were made from Plot No. 1 to No. 15; for the second set from Plot No. 8 to No. 15 and from Plot No. 7 to No. 1; and finally the third set, from Plot No. 15 to No. 1; and so on.

These procedures were applied to the Campus data as well as to data for four kinds of photographic paper. All measurements of tree height were made by use of the modified techniques described below. All estimates of crown width and crown closure were determined with these new techniques except the first 3 sets of measurements which were made before the modified technique was developed.

(b) Tree height

For each plot, four estimates of the average height of dominant and codominant trees were made with the Abrams height-finder. The writer followed the training program prescribed by Johnson (1958a) before measuring the heights of trees. It was found that error of tree-height measurements was reduced from ± 5 feet to ± 2 feet on measuring heights of 8 open grown trees ranging from 51 to 79 feet in height.

Technique of measuring tree height. Figure 1 illustrates measurement of tree height. It has been the writer's experience that, while measuring a tree, the distance between the interpreter's eyes and lenses of the stereoscope should be held at some fixed distance within the range of 0.5 to 1.0 inch. The dot of the height-finder should be in a position 1 to 2 mm. from the side of the tree crown, preferably the right-hand side in the 4- to 5- o'clock position if local conditions permit. After the dot has been raised to the level of the top of the tree crown, the interpreter should then move his head slightly to and fro from left to right. At the same time, the dot moves in the opposite direction to the interpreter's field of view. This enables the interpreter to see whether or not the dot appears to coincide with the top of the tree. The same procedure is required for the interpreter to obtain the parallax reading at the bottom of the tree. Then a good estimate of parallax difference can be obtained. The stands were sufficiently open to permit direct measurement of ground level within each plot in most cases. Salal was the most prominent shrub and did not exceed 3 feet in height but understory hemlock and cedar were numerous in many stands.

It is the writer's opinion that in addition to the usual method (Avery 1957, pp. 21-25), the above approach would be useful in the instruction of photo-interpreters.

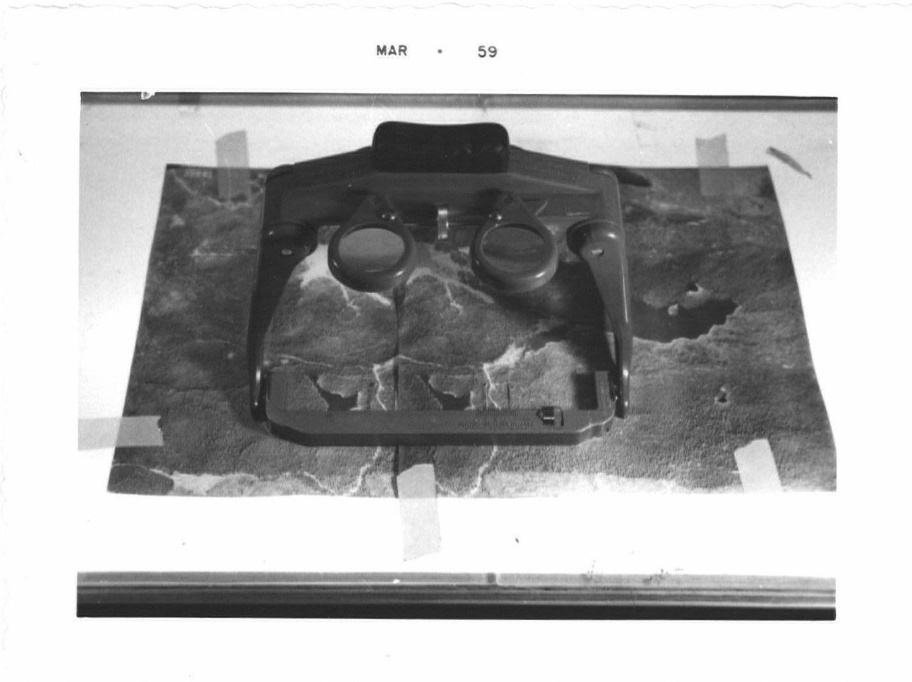

Figure 1

The measurement of tree height

(c) Crown width

Four estimates of crown width were made on each of the tallest trees on each plot.

Technique of measuring crown width. Two dot-type scales were used in an attempt to get improved results in the estimation of crown width. A scale was put on each of the two photographs under the stereoscope for comparison with the same tree crown. When the interpreter is sure that the tree crown would be covered entirely by the right-hand pair of dots, these are shifted onto the tree crown for a direct check on crown width. The size of the tree crown is thus determined accurately. The two dots, one on each of the photographs provide a third-dimension view of the dot as well as of the tree crown itself. This approach, which is a modification of the usual method (Jensen 1948), could be helpful in the instruction of photo-interpreters. Figure 2 shows how the measurement of crown width was made.

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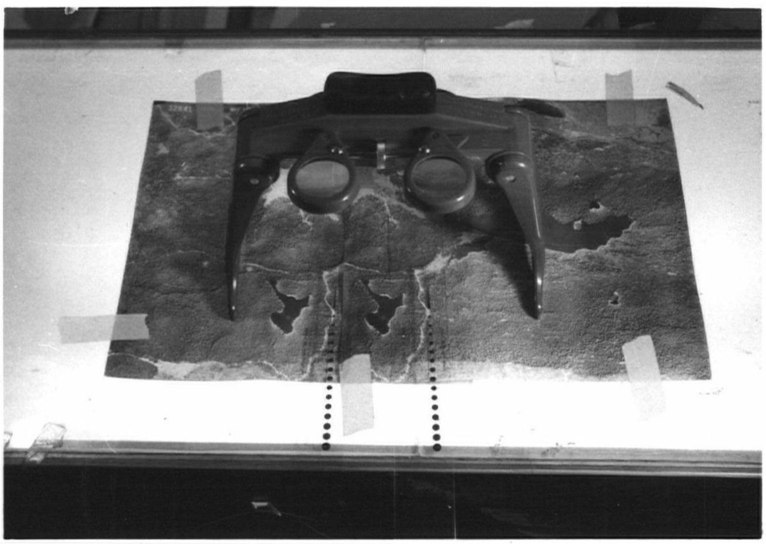

Figure 2

The Measurement of crown width

(d) Crown closure

One estimate of the portion covered by tree crowns was made for each plot.

Technique in estimating crown closure. Use of two crown-closure scales gives better results in the estimation of stand density than the usual single scale. A piece of white paper attached to the lower surface of each scale also will increase the contrast between the black and transparent portions. This provides a clear view when scales are put under the stereoscope. The same procedure as for the measurement of crown widths, i.e., use of a double scale in a stereoscopic view, is required to estimate the crown closure as a percentage. Again, this provides a third-dimension view of the scale as well as the plot itself as a comparison. Figure 3 shows the physical set-up for the measurement of crown closure.

Under-story trees were included in the estimate of crown closure.

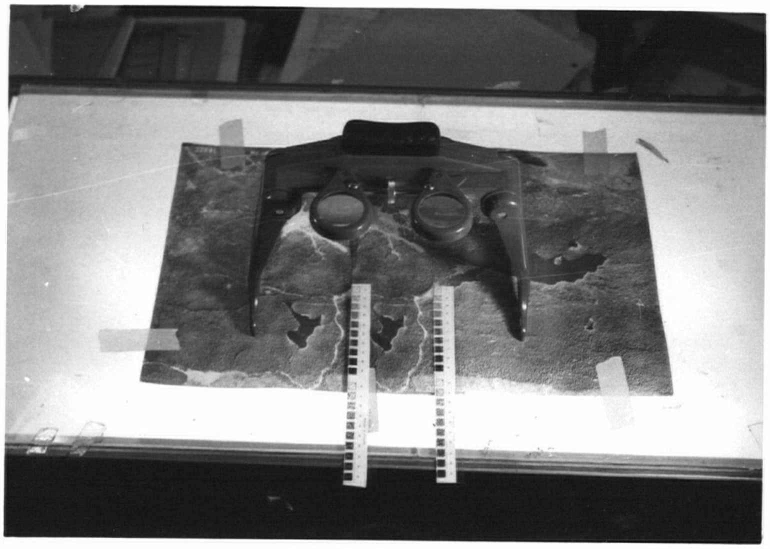

Figure 3

The estimate of crown closure

2. Operators

Operator A, the writer of this thesis, has taken photogrammetry courses continuously since the spring of 1957, and has done some height measurement periodically throughout that time. Before taking photo measurements for this study, he reached a level of competency enabling him to measure consistently the heights of open-grown trees with a maximum error of less than 4 feet on photographs with an RF of approximately 1:15,000. Detailed knowledge of some of the photographs and stands concerned was obtained during a summer spent at the U.B.C. Research Forest at Haney, where these sample plots are located.

Operator B took a one-term introductory course in photogrammetry in the spring of 1957. He has studied photo-interpretation since the fall of 1958 and has an excellent academic record in this field. He spent one month at the Research Forest in the summer of 1958, and laid out some of the sample plots on the Campus Forest.

Operator C took one elementary photogrammetry course and spent one month at the Research Forest.

Operator D is an inexperienced photo-interpreter who has not visited either the Research Forest or Campus Forest.

Operators E and F are photo-interpreters with many years of experience, but neither has visited the areas studied.

Operator G is a composite made up of a group of 11 students, with little experience in photo-interpretation but with considerable familiarity with the Campus Forest.

3. Photographs used

Five sets of photographs (1,2,3,4 and 5), were used for the study of photo-mensurational problems, and another two sets (6 and 7) were used for forest typing. Information on these photographs is as follows:

Table 2

Specifications of aerial photographs used

Set No.	Date of Photography	Name of Camera	Focal Length, in.	Flying Height, ft.	Size of photographs in.
1	July 1955	Ross	12	15,900	9 x 9
2	May 1958	Ross	12	15,600	9 x 9
3	May 1958	Wild RC8	6	8,400	9 x 9
4	May 1958	Wild RC8	6	15,600	9 x 9
5	Aug. 1957	Wild RC8	6	8,220	9 x 9
6	July 1954	Williamson F-52	20	15,600	7 x 8 1/2
7	July 1954	Williamson F-52	20	7,870	7 x 8 1/2

Panchromatic film was used for all photography, and all strips were run northward. Sets 1 to 5 were taken by

Photographic Survey Corp. Ltd.; Sets 6 and 7 were taken by Aero Surveys Ltd., both of Vancouver, Canada.

4. Photographic paper or finishes

Four kinds of photographic papers or finishes, viz., positive transparency, Gevaert paper, and semi-matte and glossy finishes were processed for sets 2, 3, and 4 in order to determine if significant differences in photo-measurements existed among them. All photographs were processed by Photographic Survey Corp. Ltd.

Compilation of data collected in the field

Site index was estimated for each plot using average height of dominant and codominant trees in order to facilitate the use of U.B.C. Research Forest and U.B.C. Campus Forest tree-volume tables. In using these tables to obtain the cubic-foot volumes, trees were sorted into 1-inch d.b.h. classes by species. Total cubic-foot volumes for all species on each plot were used to find total cubic-foot volumes per acre for each plot. At the same time, numbers of trees per plot were counted and then converted into total number of trees per acre for each plot.

ANALYSIS OF DATA

Method

1. Multiple linear regression

It has been found that correlations between total cubic-foot volumes (based on ground data), and the variables, tree height, crown width, and crown closure (which are measureable on aerial photographs) are generally statistically significant (Gingrich and Meyer 1955, Allison 1955, Dilworth 1956, and Smith 1957). These are usually determined by analysis of multiple linear regression equations involving the determination of the average value of the dependent variable in terms of a number of independent variables. The equations measure the combined influence of all independent variable on the dependent variable (Snedecor 1956).

The usual form of the multiple linear regression equation is as follows:

$$V = a + b_1(Ht) + b_2(CW) + b_3(CC)$$

where V is the total gross cubic-foot volume per acre (based on ground data).

Ht is the average height of 4 dominant and codominant trees as measured with an Abrams height finder on aerial photographs.

CW is the average crown width of 4 dominant and codominant trees as measured with U.B.C. Crown-width scales on aerial photographs.

CC is the crown closure, in per cent, as estimated on aerial photographs by comparison with U.B.C. Crown-closure scales.

b_1, b_2, and b_3 are regression coefficients derived from the data by the least-squares solution, and

a is the value of V when all independent variables are 0.

The correlation coefficient is a measure of the closeness of the relationship, or degree of association, among dependent and independent variables sampled. It is defined as the square root of the net sum of products removed by regression divided by the net sum of squares of the dependent variable. If the correlation coefficient equals one there is a perfect correlation. The closer the value of the correlation coefficient approaches one, for a given number of degrees of freedom, the more significant will be the association in the data sampled.

Multiple linear regressions were derived for each set of photo-measurements and ground-measured volume. Then the sum of squares removed in the multiple regression equation by each of stand height, crown width, and crown closure, and multiple correlation coefficients were calculated as a basis for comparison. The higher the significance of the multiple linear regression, the better will be the set of photographs for photo-mensurational purposes. The greater the sum of squares removed by regression, the more reliable will be that variable for photo-measurements used in determination of photo-volumes. The larger the sum of squares of the individual independent variables, the more will be their contribution to the significance of the regression, with a corresponding increase in the value of the correlation coefficient.

2. Use of the Electronic computer Alwac III-E

The U.B.C. Computing Centre provides a program for computing means, standard deviations, correlation and covariance matrices, and regression coefficients for from one to eight variables. This was used to solve all the multiple linear regressions in this study in order to avoid tedious manual calculations. Data for input are arranged as follows:

$$X_{11},\ X_{12}\ \text{----------------}\ X_{n},\ X_{1k}$$

$$X_{21},\ X_{22}\ \text{----------------}\ X_{2n},\ X_{2k}$$

$$\text{--------------------------------}$$

$$X_{N1},\ X_{N2}\ \text{----------------}\ X_{Nn},\ X_{Nk}$$

where $(X_{11}, X_{12},$ ----- $X_{N1})$ is the dependent variable * (total cubic-foot volumes in this case), $(X_{12}, X_{22},$ ----- $X_{N2})$, $(X_{13}, X_{23},$ ----- $X_{N3})$, ---------, and $(X_{1n}, X_{2n},$ -----$X_{Nn})$ are all independent variables $(X_{12}, X_{22},$ -----X_{N2} are tree heights; $X_{13}, X_{23},$ ----- X_{N3} are crown widths; and $X_{14}, X_{24},$----- X_{N4} are crown closures in this case). X_{1k} is equal to the sum of $(X_{11}, X_{12}, X_{13},$ ----- $X_{1n})$; X_{2k} is equal to the sum of $(X_{21}, X_{22}, X_{23},$----- $X_{2n})$; and so on. Then $(X_{11}, X_{21},$ ----- $X_{N1})$ is dependent on $(X_{12}, X_{22},$ ----- $X_{N2})$, $(X_{13}, X_{23},$ ----- $X_{N3})$, -----, and $(X_{1n}, X_{2n},$ ----- $X_{Nn})$.

N is the number of subjects, n is the number of observations per subject including the dependent variable, X_{ij} is the j^{-th} observation on the i^{-th} subject, and where all summations are over k.

Outputs then will be computed by the computer in the following way (Hull, 1958).

The means: $M_j = \sum X_{kj}/N$,

The standard deviations: $\sigma_j = \sqrt{C_{ij}}$ (see below),

The correlation matrix elements:

$$r_{ij} = \frac{C_{ij}}{\sigma_i \sigma_j},$$

*Usually $(V_{11}, V_{21},$-----$V_{N1})$ is the independent variable, but $(X_{11}, X_{21},$ ----- $X_{N1})$ is substituted for $(V_{11}, V_{21},$ ----- $V_{N1})$ in order to simplify the expression in this program.

The covariance matrix elements:

$$C_{ij} = (N\Sigma X_{Ki}X_{Kj} - \Sigma X_i \Sigma X_j)/N(N-1),$$

-and the coefficients for the regression of the first on the remaining n-1 variables. These coefficients are obtained by solving (for b_2, b_3, b_4 ----- b_n) the equations:

$$b_2C_{22} + b_3C_{23} + \text{-----} + b_nC_{2n} = C_{21}$$

$$b_2C_{32} + b_3C_{33} + \text{-----} + b_nC_{3n} = C_{31}$$

$$b_2C_{n2} + b_3C_{n3} + \text{-----} + b_nC_{nn} = C_{n1}$$

where b_2, b_3, ----- b_n are coefficients.

C_{22}, ----- C_{2n}----- C_{3n} ----- C_{nn} are variances or covariances.

When the calculation is completed (within three minutes in this case), the outputs of the means, standard deviations, and covariance matrix elements are given to two decimal places; the correlation matrix elements and the regression coefficients are given to four decimal places. None of the calculation is checked by the computer itself, but each element of the matrices is calculated separately so that symmetry of these matrices is a check on all the calculations except for those involved in finding the regression coefficients. The regression coefficients are obtained by systematic elimination and back substitution in the solution of the normal equations. However, using a Friden calculator, the writer checked that results secured by use of the correlation coefficients and regression coefficients were identical in both cases.

U.B.C. Research Forest Data

The following tables show the correlation among total cubic-foot volume per acre measured on the ground and other ground measurements, or among ground volume and photo measurements for the 15 0.2-acre plots from the Research Forest. The net sum of squares of ground volume was 653.92. Sum of squares removed by regression varies with interpreters, variables used, ground measurements, or scale of photography.

Table 3 indicated the sum of squares removed by regression and multiple correlation coefficients for ground data after thinning (in 1956). Average height and crown width were based on all dominant and codominant trees on each plot for regression numbers 1, 2, 3, and 4; and average height and crown width were based on the 5 tallest trees for regression numbers 5 and 6.

Degrees of freedom and variables for regression numbers 1, 2, 3, 4, 5, and 6 were (9, 6), (11, 4), (11, 4), (12, 3), (11, 4) and (12, 3) respectively.

Table 3

Sum of squares removed by regression and multiple correlation coefficients for ground data ater thinning

Regression#	Sum of Squares Removed by Regression (Ht)	(CW)	(CC)	(NT)+	(V/T)++	Multiple Correlation Coefficient(R)
No. 1 (V) on (Ht),(CW),(CC),(NT), & (V/T)	211.89	64.22	42.73	240.19	156.66	0.980 **
No. 2 (V) on (Ht),(CW), & (CC)	204.18	52.51	105.02	-	-	0.744 *
No. 3 (V) on (Ht),(NY), & (V/T)	218.75	-	-	202.04	176.18	0.955 **
No. 4 (V) on (Ht), & (CC)	240.18	-	101.87	-	-	0.723 *
No. 5 (V) on (Ht),(CW), & (CC)	354.17	87.57	72.78	-	-	0.887 **
No. 6 (V) on (Ht), & (CW)	379.69	72.45	-	-	-	0.822 **

\# : Net sum of squares of ground volume:653.92

* : Significant at 5% level

** : Significant at 1% level

\+ : (NT) is number of trees per acre

++ : (V/T) is cubic-foot volume per tree

Table 4

Sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 2.

	Regression #	Opr.	Trial	Sum of squares Removed by Regression (Ht)	(CW)	(CC)	(NT)	Multiple correlation coefficient (R)
No. 1	(V) on (Ht),(CW), & (CC)	A	First	113.25	2.32	283.78	-	0.781 *
No. 2	(V) on (HT), & (CC)	A	First	116.04	-	283.26	-	0.781 **
No. 3	(V) on (Ht), (CW), & (CC)	A	Second	123.67	21.51	345.14	-	0.868 **
No. 4	(V) on (Ht), (CW), (CC) & (NT)	A	Second	92.43	18.98	419.58	-33.27	0.872 **
No. 5	(V) on (Ht), (CW), & (CC)	B	First	31.21	267.40	25.08	-	0.704 *
No. 6	(V) on (Ht), & (CW)	B	First	69.28	127.42	-	-	0.548 N.S.
No. 7	(V) on (Ht), (CW), & (CC)	B	Second	317.25	110.40	47.08	-	0.852 **
No. 8	(V) on (Ht), (CW), & (CC)	E	First	98.35	2.72	-.87	-	0.391 N.S.
No. 9	(V) on (Ht), (CW), & (CC)	F	First	10.65	22.64	35.19	-	0.324 N.S.

: Net sum of squares of ground volume: 653.92

N.S.: Not significant

Table 5

Sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 3.

Regression #		Opr.	Trial	Sum of Squares Removed by Regression (Ht)	(CW)	(CC)	(NT)	multiple correlation coefficient (R)
No. 1	(V) on (Ht),(CW), & (CC)	A	First	8.68	83.61	269.25	-	0.743 *
No. 2	(V) on (CW), & (CC)	A	First	-	89.78	271.39	-	0.743 **
No. 3	(V) on (Ht),(CW), & (CC)	A	Second	50.64	126.06	236.71	-	0.795 **
No. 4	(V) on (Ht),(CW),(CC), & (NT)	A	Second	45.26	120.62	258.65	-10.05	0.796 *
No. 5	(V) on (Ht),(CW), & (CC)	B	First	94.37	8.21	4.12	-	0.404 N.S.
No. 6	(V) on (Ht), & (CW)	B	First	96.75	3.05	-	-	0.381 N.S.
No. 7	(V) on (Ht),(CW), & (CC)	B	Second	356.31	30.34	-2.46	-	0.767 *

: Net sum of squares of ground volume: 653.92

Table 6

Sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 4.

Regression #	Opr.	Trial	Sum of squares Removed by Regression (Ht)	(CW)	(CC)	(NT)	Multiple correlation coefficient (R)
No. 1 (V) on (Ht),(CW) & (CC)	A	First	171.41	73.10	59.68	-	0.682 N.S.
No. 2 (V) on (Ht) & (CC)	A	First	203.37	-	88.08	-	0.682 *
No. 3 (V) on (Ht),(CW) & (CC)	A	Second	65.25	78.78	276.30	-	0.831 **
No. 4 (V) on (Ht),(CW),(CC) & (NT)	A	Second	42.05	26.54	390.97	-29.08	0.811 *
No. 5 (V) on (Ht),(CW) & (CC)	B	First	0.40	87.77	-1.37	-	0.364 N.S.
No. 6 (V) on (Ht) & (CW)	B	First	0.58	84.67	-	-	0.361 N.S.
No. 7 (V) on (Ht),(CW) & (CC)	B	Second	278.57	208.98	41.83	-	0.826 **

: Net sum of squares of ground volume: 653.92

Table 7

Sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 1 (before thinning)

Regression#	Opr.	Trail	Sum of squares removed by regression (Ht)	(CW)	(CC)	Multiple correlation coefficient (R)
No. 1 (V) on (Ht) (CW) & (CC)	A	First	19.33	-8.89	612.76	0.941 **
No. 2 (V) on (Ht) (CW) & (CC)	C	First	145.03	135.28	152.32	0.784 *
No. 3 (V) on (Ht) (CW) & (CC)	D	First	157.15	0.30	1.89	0.476 N.S.

: Net sum of squares of ground volume: 653.92

Table 8

Simple correlation coefficients# of photo estimate of number of trees for photographs of Sets No. 2, 3, and 4 based on total number of trees on plot and on trees 12.6 inches in d.b.h. and larger

Number of trees on plot on ground	Simple correlation coefficient (r) Photo Set No. 2	Photo Set No. 3	Photo Set No. 4
	Photo estimate correlated with ground count		
Total	0.814 **	0.887 **	0.839 **
12.6" +, d.b.h.	0.385 N.S.	0.405 N.S.	0.281 N.S.

: Degrees of freedom: $n_1 = 2$, $n_2 = 13$ * : Significant at 5% level: 0.514

** : Significant at 1% level: 0.641

Table 4 indicated the sum of squares removed by regression and multiple correlation for photographs of Set No. 2 which was taken with a camera possessing a 12-inch focal-length lens, at a flying height of 15,600 feet above sea level.

Degrees of freedom and variables were 11 and 4 respectively, for Regression No. 1, 3, 5, 7, 8, and 9; 12 and 13 for Regression No. 2 and 6; and 10 and 5, respectively for Regression No. 4.

Table 5 shows the sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 3, taken by a 6-inch focal-length camera at a flying height of 8,400 feet above sea level.

Degrees of freedom and variables used were 11 and 4, respectively, for Regression No. 1, 3, 5, and 7; 12 and 3 for Regression No. 2 and 6; and 10 and 5, respectively, for Regression No. 4.

Table 6 shows the sum of squares removed by regression and multiple correlation coefficients for photographs of Set No. 4, taken with a 6-inch focal-length-lens camera and a flying height of 15,600 feet above sea level.

Degrees of freedom and variables used were 11 and 4, respectively, for Regression No. 1, 3, 5, and 7; 12 and 3 for

Regression No. 2 and 6; and 10 and 5 for Regression No. 4.

For Table 7, based on photos taken before thinning, the new sum of squares of ground volume was 703.38 for the same 15 0.2-acre sample photos represented in Table 1 to 7. Table 7 indicates the sum of squares removed by regression and multiple correlation coefficients for Set No. 1 with photographs taken with a 12-inch focal-length-lens camera and a flying height of 15,900 feet above sea level.

Degrees of freedom and variables were 11 and 4, respectively, for all regressions.

In order to evaluate the relative importance of the count of number of trees from aerial photographs as a variable in the determination of photo volume, numbers of trees determined on photographs of set No. 2, 3, and 4, were correlated with total number of trees on plot and number of trees 12.6 inches in d.b.h. and over. The simple correlation coefficients were calculated and the results tabulated in Table 8.

This shows that, although number of trees counted from photographs was highly significant with total number of trees on plot, it did not remove any sum of squares from the regression and did not increase significantly the multiple correlation coefficient (R). (See Table 4,5, and 6).

U.B.C.Campus data

The following tables show the correlations of total cubic-foot volume with ground measurements and with photo-measurements for 84, 0.1-acre plots and 40 0.1-acre plots respectively, from the Campus Forest.

The net sums of squares of ground volume were 589.61 and 570.15 for the 84 0.1-acre and 40 0.1-acre plots, respectively. Sum of squares removed by regression varies with interpreters, variables used, and ground measurements. (Table 9 on following page).

√ Analysis of variance on four kinds of photographic paper or finishes

In order to determine if there was a significant difference between photographic papers and various scales of photography used in the estimation of photo measurements, a sub-project was set up.

For each set of the photographic papers, photo measurements, including tree height, crown width, and crown closure, were made on three out of the 15 0.2-acre plots representing stands with the highest, an average, and the lowest volumes per acre. An equation was fitted to these data by the method of least squares using the Electronic Computer Alwac III-E. The following regression was found:

Table 9

Sum of squares removed by regression and multiple correlation coefficients for Set No. 5 (campus photographs, focal length = 6 inches, flying height = 8,200 feet).

Regression		Operator	Trial	No. of 0.1-acre plots	Sum of squares Removed by Regression (Ht)	(CW)	(CC)	multiple correlation coefficient (R)
No. 1	(V) on (Ht), (CW) & (CC)	(ground)	-	84	57.14	36.06	25.50	0.449 **
No. 2	(V) on (Ht), (CW) & (CC)	G	First	84	66.03	9.95	38.49	0.441 **
No. 3	(V) on (Ht), (CW) & (CC)	(ground)	-	40	60.18	9.30	24.01	0.405 N.S.
No. 4	(V) on (Ht), (CW) & (CC)	A	First	40	7.45	14.16	188.70	0.607 **

* $n_1 = 4$, $n_2 = 80$, significant at 5%; 0.304

** $n_1 = 4$, $n_2 = 80$, significant at 1%; 0.362

* $n_1 = 4$, $n_2 = 35$, significant at 5%; 0.445

** $n_1 = 4$, $n_2 = 35$, significant at 1%; 0.523

(cubic-foot volume, per acre, on ground) = 0.5938 (Height, in feet)
+ 1.8522 (crown width, in feet) + 2.1321
(crown closure, in per cent) - 188.29.

This correlation coefficient for the regression was 0.963 (significant at 1% level). The net sum of squares of ground volume amounted to 1482.74, and the sums of squares removed by regression were 385.09, 127.78, and 862.46 for height, crown width, and crown closure, respectively.

Total cubic-foot volumes per acre for each plot were then calculated by using the above regression for each set of photographic papers and scales. The result of an analysis of variance of photo volume is as follows:

Table 10

Analysis of variance of photo volume

Sources of variation	Degrees of freedom	Sum of squares	Mean squares	F
Plots	2	46251.56	23125.78	355.946 **
Papers	3	108.75	36.25	0.558 N.S.
Scales	2	2.73	1.37	0.021 N.S.
Remainder	28	1819.27	64.97	

It is evident that, in this study, there is a highly significant difference among plots, but there are no significant-differences among scales or photographic papers used in making volume estimations.

Analysis of forest typing

The first step in the delineation of forest types is to draw in the boundaries of each change in stand size, species composition, or stand density. This can be done from photographs of RF 1:20,000 or smaller.

Identification of species is based upon tone, crown shape, texture and pattern, shadow shape, and ecological data. Tone is especially useful for differentiation between hardwoods and conifers, since hardwoods are much lighter in tone than conifers. It was found that these could be separated without any difficulty on the photographs studied.

The features most useful for the identification of second-growth Douglas fir are very fine texture, a more or less conical crown, the upward branching habit, and a very erect leader. Western hemlock has the same characteristics as Douglas fir under the stereoscope, except that it has a drooping leader, which cannot be seen distinctly, and a feathery appearance to its crown. Western red cedar is light in tone, and usually has a long, dense crown that is spire-like in appearance. Its leader and branches are drooping. White pine has a fairly symmetrical crown with a star shape under the stereoscope; whereas the crown of silver fir is rounded, dense, dome-like, and conical in shape.

By applying these known characteristics to photo-interpretation, Douglas fir and western hemlock can be distinguished from western red cedar, silver fir, and western white pine only in open stands and only in some cases for photographs of Set No. 4. But these two groups of species can be separated within the stands in most cases for photographs of Set No. 1, 2, 3, and 5. One familiar with local conditions can distinguish between stands of Douglas fir and western hemlock in some cases. On the other hand, using the large-scale long-focal-length photographs of Set No. 6 and 7, branching characteristics, textural differences in foliage, and shape and size of crown can be applied as a key for the identification of all species on photographs of Set No. 7, and occasionally on Set No. 6. The writer can distinguish any tree on photographs of Set No. 7 under stereoscope without any trouble. He feels that photographs of set No. 1, 2, 3, and 5 would be satisfactory where an estimate of species composition in percentage only is needed. Among these photographs, Set No. 7 is the best for species identification and forest typing.

Form of the best equation

The U.B.C. Computing Centre provides another program developed by Dr. C. Froese for computing means, standard deviations, correlation and covariance matrices, and regression coefficients for from 1 to 32 variables. This program calculates various specified powers or combinations of the original variables.

This program was used to find out the form of the best equation. Twenty single or combined variables of tree height, crown width, crown closure, and number of trees per plot, which were the best photographic estimates made by operator A, were correlated with ground volume. The following table shows the simple correlation coefficients of ground volume with each of the 20 variables.

Variables	(Ht)	(CW)	(CC)	(Nt)*	$(Ht)^2$	$(CW)^2$
correlation coefficient	.637	.450	.807	.306	.644	.465

$(CC)^2$	$(Nt)^2$	(Ht)(CW)	(Ht)(CC)	(Ht)(Nt)	(CW)(CC)	(CW)(Nt)
.824	.299	.629	.817	.621	.791	.469

(CC)(Nt)	(Ht)(CW)(CC)	(Ht)(CW)(Nt)	(Ht)(CC)(Nt)	(CW)(CC)(Nt)	$(Ht)^2(CC)$	$(Ht)(CC)^2$
.490	.773	.667	.703	.601	.752	.865

* Nt : is number of trees on a 0.2-acre plot counted on an aerial photograph under a stereoscope.

Therefore, the variables giving the best equations will be: (1), $(Ht)(CC)^2$; (2), $(CC)^2$; (3), (Ht)(CC); and (4), (CC).

OBSERVATIONS

Influence of operator

The most difficult problem in photo-interpretation is the variation that exists among photo interpreters. As the photo interpreter is a human being, he cannot be compared with a mechanical instrument which can be adjusted, or repaired. Thus, photo-interpretation is more of an art than a science.

The following table shows the variation in results from interpreter to interpreter.

From Table 11, (see page 65) interpreter A would consistently favor the use of crown closure as the most important variable in the estimation of ground volume, because the greatest portion of sum of squares was removed by the use of crown closure. Interpreter B consistently found tree height the most important variable. Regressions of both A and B were highly significant in most cases (See table 11: multiple correlation coefficients). Other interpreters, C and F, would agree with interpreter A in use of crown closure, whereas interpreters, D, E, and G, would agree with interpreter B, preferring the use of tree height. Pope (1957) and others have found similar variation in results from interpreter to interpreter. The development of new techniques in actual determination of photo-measurements, rather than of equipment

Table 11

Results from regressions of correlations between volume and photo-measurements of tree height, crown width, and crown closure

Degree of Freedom	Operator	Photo Set No.	Trial	Sum of squares removed by regression (Ht)	(CW)	(CC)	multiple correlation coefficient (R)
11.4	A	1	First	19.33	-8.89	612.76	0.941 **
11.4	A	2	First	113.25	2.32	283.78	0.781 *
11.4	A	2	Second	123.67	21.51	345.14	0.868 **
11.4	A	3	First	8.68	83.61	269.25	0.743 *
11.4	A	3	Second	50.64	126.06	236.71	0.795 **
11.4	A	4	First	171.41	73.10	59.68	0.682 N.S.
11.4	A	4	Second	65.25	78.78	276.30	0.831 **
35.4	A	5	First	7.45	14.16	188.70	0.607 **
11.4	B	2	First	31.21	267.40	25.08	0.704 *
11.4	B	2	Second	317.25	110.40	47.08	0.852 **
11.4	B	3	First	94.37	8.21	4.12	0.404 N.S.
11.4	B	3	Second	356.3	30.34	-2.46	0.766 *
11.4	B	4	First	0.40	87.77	-1.37	0.364 N.S.
11.4	B	4	Second	278.57	208.98	-41.83	0.826 **
11.4	C	1	First	145.03	135.28	152.32	0.784 *
11.4	D	1	First	157.15	0.39	1.89	0.476 N.S.
11.4	E	2	First	98.35	2.72	-0.87	0.391 N.S.
11.4	F	2	First	10.65	22.64	35.19	0.324 N.S.
76.4	G	5	First	66.03	9.95	38.49	0.441 **

or photographs, might lead the individual interpreter to obtain better and more consistent results.

Certainly, photo-interpretation could be improved by the standardization of photo-interpretation procedures while using:

1. Better equipment
2. High-quality photographs with a suitable scale
3. A training program to obtain consistent and reliable results from photo-interpreters, such as the program prescribed by Johnson (1958)
4. Better techniques in photo-measuring, such as those suggested by the writer.
5. Periodic tests of the photo-interpreter's health and eye-sight (Rabben 1955)
6. Better knowledge of local conditions
7. Reducing human bias by use of a double-sampling approach (Allison and Breadon 1958).

<u>Influence of locality or region</u>

From this study, it was concluded that a knowledge of local conditions is of paramount importance in the process of photo-interpretation. Trees of the same species growing in different localities may differ from one another in many respects. A photo-interpreter could be an expert in one region but initially poor in another. Excellent results can be obtained after experience accumulates in one particular district. The following table shows that the more the interpreter knew of local conditions, the better the results that were obtained by using the same photographs.

Table 12

Correlation coefficients for various interpreters using photographs from Set No. 2

Operator	Trial	Multiple Correlation Coefficient (R)
A	First	0.781 *
A	Second	0.868 **
B	First	0.704 *
B	Second	0.852 **
E	First	0.391 N.S.
F	First	0.324 N.S.

The same photographs (Set 2) and procedures were used to obtain the multiple correlation coefficients of the relation between ground volume and photo-measurements. It seems important that Interpreter A, who obtained the best estimates (see Table 12), spent a summer in the area studied, that Interpreter B, second only to Interpreter A, spent only a month in the same area, and interpreters E and F, although with a number of years of experience in photo interpretation, obtained poor results. Neither of them had visited the area studied.

Influence of equipment

It has been the writer's experience that the Abrams Height-finder is the best instrument for measuring tree heights, especially in a very dense stand or while using photographs of poor quality. He feels that tree images are too small to get precise estimates with a parallax bar when they are studied without magnification under a mirror stereoscope. It is very difficult to get parallax readings on the tip and at the base of trees in a very dense stand.

Worley and Landis (1954) found that slightly less error was obtained by use of the Abrams Height-finder as compared with the parallax wedge.

Harper and Chester (1955), in a comparison and evaluation of different methods of measuring tree height on aerial photographs in a report for the senior photogrammetry course, found that the least average error of estimate was secured by using an Abrams C.B.I. with 2-power stereoscope and an Abrams Height-finder. Four open-grown Douglas-fir trees, 72, 113, 155, and 209 feet in height, respectively, located at the U.B.C. Research Forest, Haney, were selected for the study. The following results were obtained.

Equipment	Average error of estimate in feet
1. Abrams C.B.I. with 2 power stereoscope and Abrams Height-finder	-0.87
2. Pocket Stereoscope and Abrams Height-finder ..	+1.62

3.	Abrams C.B.I. with 4-power stereoscope and Abrams Height-finder	-2.87
4.	Abrams C.B.I. with 2-power stereoscope and Robinson Parallax wedge	-5.75
5.	Mirror stereoscope and Parallax bar	-17.40
6.	Abrams C.B.I. with 2-power stereoscope and O.S.C. Parallax wedge	-19.30
7.	Radial displacement on single photograph	-20.30
8.	Shadow method	-41.00

Some foresters prefer the use of a parallax wedge (Moessner and Rogers 1957), because it is simple, fast to handle, and inexpensive. It is the writer's opinion that, if one wishes to obtain more accurate and reliable estimates of tree height, an Abrams Height-finder is essential, especially for the inexperienced photo-interpreter. Of course, the most important factor may be the interpreter's familiarity with the instrument to be used.

Influence of technique

Judging from the experience gained in this study, the new techniques employed were of great assistance in the determination of photo measurements; they were simple, accurate, and yeilded satisfactory results.

A test will be carried out at a later date to confirm the value of these new techniques. However, it seems that the techniques described could be of great help in the photo-interpretation process.

Influence of variables

Independent variables to be used in the construction of the photo-volume regression equation are of paramount importance. In order to determine the relative importance of these independent variables, four multiple regression equations were derived, based on ground data and 19 multiple regressions determined by all operators.

1. The writer checked the individual simple correlation coefficients of volume on height, crown width, and crown closure. Significance was found for volume on height in 3 out of 4 regressions based on ground data, for volume on crown width in 2 out of 4, and for none of the 4 for ground-determined crown closure. Significance was found for volume on crown closure in 10 out of 19 regressions based on photo-data, 9 out of 19 for height, and 3 out of 19 for crown width.

2. Totals of 27.4, 9.2, and 7.5 per cent respectively, of the net sum of squares of ground volume were removed from the multiple regressions of volume on height, crown closure, and crown width, respectively, when based on ground data. Based on photo data, 20.4, 17.0, and 10.3 per cent of the net sum of squares of ground volume were removed from the multiple regression equations by crown closure, height, and crown width, respectively.

3. Finding rank in size of the net sum of squares of ground volume removed by height, crown width, and crown closure, it was found that the average ranks were 1.00, 2.50, and 2.50 for height, crown width, and crown closure, respectively, when based on ground data. (1 is the best, 2 next, and 3 poorest). Ranks were 1.84, 1.95, and 2.21 for height, crown closure, and crown width, respectively, when based on photo data.

From the above information, the following conclusions may be drawn:

<u>Ground Data</u>

(a) When ground volume was correlated individually with height, crown width, or crown closure, height was the best, crown width next, and crown closure was not significant.

(b) In all cases, height was the best variable.

(c) Both crown width and crown closure were poor because these were difficult to estimate on the ground. Poor results were obtained with crown closure because of understory vegetation which could not be eliminated from estimates made by the spherical densiometer.

<u>Photo data</u>

(a) Both crown closure and height were the best variables for the determination of photo volume.

(b) Although crown width was not as satisfactory as crown closure or height, it did remove 10 per cent of the total sum of squares of ground volume, which was one-half of the amount removed by crown closure.

(c) Height, crown width, and crown closure should be used as independent variables for the construction of photo-volume tables, especially when more than one interpreter is needed.

Influence of scale and photographic papers or finishes

In the present study, no significant difference was found among scales or photographic papers used in the determination of volume estimates.

This does not necessarily mean that similar results would be obtained under all circumstances. The amount of variability among different interpreters and the resulting photo-measurements is too great, consequently, it is dangerous to draw conclusions from the results of the measurements of a single interpreter.

Measurements by both interpreters A and B showed that photographs of Set No. 2, with a scale of RF 1:15,600, were the best for photo-mensurational work, that Set No. 4, with a scale of RF 1:31,200, was next best, and that Set No. 3, with a scale of RF 1:16,800, was the poorest. The interpreters differed from one another in the use of variables for estimation. The pertinent data are summarized in Table 13.

Table 13

Results of regressions from photographs of Set No. 2, 3, and 4

Photo Set No.	Operator	focal Length in in.	Flying Height feet	Trial	Sum of squares removed by regression (Ht)	(CW)	(CC)	multiple correlation coefficient # (R)
2	A	12	15,600	First	113.25	2.32	283.78	0.781 *
2	A	12	15,600	Second	123.67	21.51	345.14	0.868 **
2	B	12	15,600	First	31.21	267.40	25.08	0.704 *
2	B	12	15,600	Second	317.25	110.40	47.08	0.852 **
3	A	6	8,400	First	6.68	83.61	269.25	0.743 *
3	A	6	8,400	Second	50.64	126.06	236.71	0.795 **
3	B	6	8,400	First	94.37	8.21	4.21	0.404 N.S.
3	B	6	8,400	Second	357.31	30.34	2.46	0.766 *
4	A	6	15,600	First	171.41	73.10	59.68	0.682 N.S.
4	A	6	15,600	Second	65.25	78.78	276.31	0.831 **
4	B	6	15,600	First	0.40	87.77	-1.37	0.364 N.S.
4	B	6	15,600	Second	278.57	208.98	-41.83	0.826 **

: Degrees of freedom and number of variables, 11 and 4, respectively

The significance of differences in photographs of Set No. 2, 3, and 4, was statistically evaluated by analysis of variance for each multiple correlation coefficient in Table 13. These multiple correlation coefficients were first transformed from r to z values according to Table VII (Fisher and Yates, 1949, p. 46).

Table 14 indicates the results of transformation from r to z values for analysis of their variance.

Table 14

Transformation from r * to z values for analysis of their variance

Operator	Trial	Photo Set No 2	Photo Set No 3	Photo Set No 4	Total
A	First	1.05	0.96	0.83	2.84
	Second	1.33	1.08	1.19	3.60
B	First	0.88	0.43	0.38	1.69
	Second	1.27	1.01	1.18	3.46
Total		4.53	3.48	3.58	11.59
Mean		1.133	0.870	0.895	-

* R value obtained from Table 13

Table 15 gives the analysis of variance for the values in Table 14.

Table 15

Analysis of variance for Table 14

Source of variation	Degrees of freedom	Sum of squares	Mean Square	Variance ratio (F)
Operator	1	0.1387	0.1387	11.185 *
Trial	1	0.5334	0.5334	41.672 **
Photo	2	0.1679	0.0840	6.774 *
op. X tri.	1	0.0850	0.0850	6.641 *
Remainder	6	0.0745	0.0124	
Total	11	0.9995		

* : Significant at 5% level; (6,1):5.99;(6,2):5.14

** : Significant at 1% level: (6,1):13.74;(6,2):10.92

Table 16 indicates the difference of means of photo Set No. 2, 3, and 4 (from Table 14) to be compared with Just Significant Differences (Snedecor 1957, p. 253).

Table 16

Difference of means to be compared with Just Significant Differences

Photo Set	Mean, $\bar{x}$	$\bar{x}$ - 0.870	$\bar{x}$ - 0.895
No. 2	1.133	0.263 * (0.242)#	0.238 * (0.193)#
No. 4	0.895	0.025 N.S. (0.193)#	
No. 3	0.870		

* : Significant

: Just Significant Difference

N.S. : Not significant

From the above information, it may be concluded:

1. Significant differences were found between operators, trials, or interaction of operator and trial.
2. Significant differences were found among photographs used.
3. Difference of means was found between photo Set No. 2 and 3, or 4. No difference was found between photo Set No. 3 and 4 in the determination of photo-measurements.

<u>Regressions based on ground data vs. regressions based on photo data</u>

In comparing the photo-estimates with the ground estimates, several multiple correlation coefficients of the photo regressions determined by Interpreters A and B were better than those based on ground data. The reasons for this difference are: (1) ground estimates of crown closure in per cent had included understory trees.

(2) Too many heights and crown widths of codominant trees, had been taken into account for the determination of the ground regression.

(3) Better measurements had been made on both heights and crown closures on aerial photographs.

(4) Crown width measured on aerial photographs also gave better results than those measured on the ground because of the bird's-eye view of the tree crowns.

A comparison of regressions based on ground data and photo data is summarized in Table 17.

Table 17

A comparison of regressions based on ground data and photo data

Photo or ground	operator	Trial	Sum of squares removed by regression (Ht)	(CW)	(CC)	Multiple correlation coefficient (R)
(ground)	-	-	204.18	52.51	105.02	0.744 *
Set No. 2	A	Second	123.67	21.51	345.14	0.868 **
Set No. 2	B	Second	317.25	110.40	47.08	0.852 **
Set No. 3	A	Second	50.64	126.06	236.71	0.795 **
Set No. 3	B	Second	357.31	30.34	2.46	0.766 **
Set No. 4	A	Second	65.25	78.78	276.31	0.831 **
Set No. 4	B	Second	278.57	208.98	-41.83	0.826 **
(ground)	-	-	60.18	9.30	24.01	0.405 N.S.
Set No. 5	A	First	7.45	14.16	188.70	0.607 **

CONCLUSIONS

In the past, many authors have reported applications of aerial photographs to forestry problems. Photogrammetry has been used mostly as an aid rather than as an essential tool. Today, with good quality photographs, better instruments, and modern machines, foresters have developed photo-mensurational techniques for direct estimation of timber volume and for reliable classification of forest types.

From the results of the current study, it has been possible to draw the following conclusions:

(1) The use of the Electronic Computer Alwac III-E was a great help in the solution of multiple regression equations for the construction of aerial-photo volume equations.

(2) The writer found that the Abrams Height-finder was an excellent instrument for measuring tree heights.

(3) Using a spherical densiometer, a ground estimate of crown closure in per cent resulted in an over-estimate, as compared with the photo estimate, because it included understory trees.

(4) Modifications of the usual techniques for the determination of photo-measurements were described and used with success.

(5) A tree count does not contribute to the removal of any variation by regression, when height, crown width, and crown closure have also been measured, since it cannot be made

sufficiently accurately on the photographs used.

(6) A relatively high multiple-correlation coefficient was obtained when ground values of average height and crown width of the five tallest trees on the plot were used as independent variables correlated with ground volume.

(7) When 3 out of 15 0.2-acre plots that had the greatest range in volume were used, the multiple correlation coefficient was 0.963.

(8) In some cases, multiple regression equations based on photo data were better than those based on ground data.

(9) Best results were secured when photographs were taken with a 12-inch focal length and a flying height of 15,600 feet above sea level.

(10) For the construction of aerial volume tables, height, crown width, and crown closure should be used as independent variables, especially when more than one interpreter is involved.

(11) Although the range in plot volumes and area sampled were quite small in this study, high multiple correlation coefficients were secured in most cases. This means that, since it is possible to work under these difficult conditions, it should be generally applicable in similar stands.

(12) No significant differences were found among photographic materials used, viz., positive transparency, Gevaert paper, and semi-matte and glossy finishes.

(13) In general, the larger the scale of the photographs, the better will be the results for forest typing. However, photography with an RF of 1:15,840 should be satisfactory.

(14) The greatest source of variation was among photo-interpreters, rather than materials and equipments used.

(15) When photo-interpreters were familiar with local conditions, better results were obtained.

(16) Photo-interpretation could be improved by the standardization of photo-interpretation procedures.

(17) Finally, more research is necessary to study and improve the human elements, that is, the photo interpreters.

BIBLIOGRAPHY

Allison, G.W. 1955. An application of an aerial photo volume table to forest inventory work in British Columbia. Forestry Chronicle. 31: 366-368.

__________. 1956. The accuracy of tree height measurements on various qualities of aerial photographs. Forestry Chronicle. 32: 444-450.

__________, and R.E. Breadon. 1958. Provincial aerial photo stand volume tables for Interior British Columbia. Forestry Chronicle. 34: 77-83.

Andrews, G.S. 1934. Air survey and forestry developments in Germany. Forestry Chronicle. 10: 91-107.

__________. 1936. Tree heights from air photographs by simple parallax measurements. Forestry Chronicle. 12: 152-197.

Avery, Gene. 1957. Forester's guide to aerial photo interpretation. Southern Forest Experiment Station. Occasional Paper No. 156. 41pp.

Bernstein, D.A. 1958. Does magnification improve measurements of stand height on aerial photographs? Forestry chronicle. 34: 435-437.

Bruce, Donald, and L.H. Reineke. 1931. Correlation alinement charts in forest research. U.S. Dept. of Agriculture, Technical Bulletin No. 210. 87 pp.

Collins, J.R. 1957. A check on the accuracy of tree heights taken from aerial photographs. Forestry chronicle. 33: 168-169.

Colwell, R.N. 1948. Aerial photographic interpretation of vegetation for military purposes. Photogram. Engineer. 14: 472-481.

__________. 1954. A systematic analysis of some factors affecting photographic interpretation. Photogram. Engineer. 20: 433-454.

Dilworth, J.R. 1956. The use of aerial photographs in cruising second-growth Douglas fir stands. Unpublished thesis for the degree of Doctor of Philosophy, University of Washington. 153 pp.

Ferree, M.J. 1953. Estimating timber volumes from aerial photographs. New York State College of Forestry. Technical Publication No.75. 50 pp.

Fisher, R.A. and F. Yates. 1949. Statistical tables for biological, agricultural and medical research. Third Edition Revised and Enlarged. Hafner Publishing Company Inc. New York. 112 pp.

Garver, R.D. and Karl E. Moessner. 1949. Forest service use of aerial photographs. Photogram Engineer. 15: 504-517.

Getchell, W.A. and H.E. Young. 1953. Length of time necessary to attain proficiency with height finders on air photos. Forestry Department, University of Maine. Technical Note No. 23. 2 pp.

Gingrich, S.F. and H.A. Meyer. 1955. Construction of an aerial stand volume table for upland oak. Forest Science 1: 140-147.

Harper, A. and G.S. Chester. 1955. Comparison and evaluation of different methods of measuring tree height on aerial photographs. Unpublished report, Faculty of Forestry, University of British Columbia, Vancouver 8, B.C., Canada. 4 pp.

Hindley, Earle, and J.H.G. Smith. 1957. Spectrophotometric analysis of foliage of some British Columbia conifers. Photogram. Engineer. 23: 894-895.

Hixon, Homer J. 1950. The use of aerial photographs in timber cruising on the National Forests. Photogram. Engineer. 16: 317-321.

Hull, T.E. 1958. Program for computing means, standard deviations, correlation and covariances, and regression coefficients for up to eight variables. U.B.C. Computing Centre, University of British Columbia, Vancouver 8, B.C., Canada. Mimeo. 5 pp.

Jensen, Chester E. 1948. Dot-type scale for measuring tree-crown diameters on aerial photographs. U.S. Forest Service, Central States Forest Experiment Station. Note No. 48. 4 pp.

Jensen, H.A. and R.N. Colwell. 1949. Panchromatic versus infrared minus-blue aerial photography for forestry purposes is California. Photogram. Engineer. 15: 201-224.

Johnson, Evert W. 1958a. A training program for men measuring tree heights with parallax instruments. Photogram. Engineer. 24:50-55.

Johnson, Evert W. 1958b. Effect of photographic scale on precision of individual tree-height measurement. Photogram. Engineer. 24: 142-152.

Ker, John W. 1953. The estimation of tree heights from air photographs. An unpublished paper submitted to Yale School of Forestry as a requirement for the degree of Doctor of Forestry. 62 pp.

Losee, S.T.B. 1951. Photographic tone in forest interpretation. Photogram. Engineer. 17: 785-799.

__________. 1953. Timber estimating from large scale photographs. Photogram. Engineer. 19: 752-762.

Lemmon, P.E. 1957. A new instrument for measuring forest overstory density. Journal Forestry. 55:667-669.

McArdle, R.E., W.H. Meyer, and Donald Bruce. 1949. The yield of Douglas-fir in the Pacific Northwest. U.S. Dept. of Agriculture. Technical Bulletin No. 201. 74 pp.

Miner, C.O. 1951. Stem-crown diameter relation in southern pine. Journal Forestry. 49: 490-493.

Moessner, Karl E. 1947. A crown density scale for photo interpreters. Journal Forestry. 45: 434-436.

__________. 1950. Principle uses of air photos by the Forest Service. Photogram. Engineer. 16: 301-304.

__________, and C.E. Jensen. 1951. Timber cruising on aerial photos. U.S.Forest Service, Central States Forest Experimental Station. Technical Paper No. 126.

__________, D.F. Brunson, and C.E. Jensen. 1951. Aerial volume tables for hardwood stands in the central States. U.S. Forest Service, Central States Forest Experiement Station. Technical Paper No. 122.

Moessner, Karl E. 1953. Photo interpretation in forest inventories. Photogram. Engineer. 19: 496-507.

__________. 1957. Preliminary aerial volume tables for conifer stands in the Rocky Mountains. U.S. Forest Service, Intermountain Forest and Range Experiment Statioh. Research Paper No. 41. 17 pp.

__________, and Earl J. Rogers. 1957. Parallax wedge procedures in forest surveys. U.S. Forest Service, Intermountain Forest and Range Experiment Station. Misc. Pub. No. 15. 22pp.

Moir, Stuart. 1936. Comments on the use of aerial photographs for forestry purposes in the United States. Forestry Chronicle 12: 61-62.

Morris, A.W. 1957. Aerial volume table for black spruce type for the northeastern coniferous zone. Canadian Pulp and Paper Assoc. Woodlands Section Index No. 1650(A-2-6). 15pp.

Nash, A.J. 1948a. Nash scale for measuring tree crown widths. Forestry Chronicle. 24: 117-120.

__________. 1948b. Some volume tables for use in air survey. Forestry Chronicle. 24: 4-14.

__________. 1949. Some tests of the determination of tree heights from air photographs. Forestry Chronicle. 25: 243-249.

Nowicki, Albert L. 1952. Elements of stereoscopy. American Society of Photogrammetry. Washington, D.C. Manual of Photogrammetry. Second Edition. p. 521-533.

Nyyssonen, Aarne. 1955. On the estimation of the growing stock from aerial photographs. Communications Instituti Forestalis, Fenniae. 46.1, 57pp.

Pope, R.B. 1950. Aerial photo volumes. Photogram. Engineer. 16:325.

__________. 1957. The effect of photo scale on the accuracy of forestry measurements. Photogram. Engineer. 23: 869-873.

Rabben, Ellis L. 1955. The eyes have it. Photogram. Engineer. 21: 573-578.

Rogers, E.J. 1958. Report of working group 4(foresters), Commission VII, International Society of Photogrammetry. Photogram. Engineer. 24: 603-616.

Seely, H.E. 1935. The use of air photographs for forestry purposes. Forestry Chronicle. 11: 287-293

__________. 1949. Air photography and its application to forestry. Photogram. Engineer. 15: 548-554.

Smith, J.H.G. 1957. Problems and potential uses of photo mensurational techniques for estimation of volume of some immature stands of Douglas fir and western hemlock. Photogram. Engineer. 23: 595-599.

Snedecor, G.W. 1956. Statistical methods. Fifth Edition, The Iowa State College Press, Ames, Iowa. 534 pp.

Spurr, Stephen H. 1945. Parallax wedge measuring devices. Photogram. Engineer. 11: 85-89.

__________. 1948. Aerial photographic techniques in forestry. Photogram. Engineer. 14: 535-537.

__________. 1954. History of forest photogrammetry. Photogram. Engineer. 20: 551-560.

__________, and C.T. Brown, Jr. 1946. Specifications for aerial photographs used in forest management. Photogram. Engineer. 12:131-141.

Thelen, Rolph. 1919. Aerial photography and national forest mapping Journal Forestry. 17: 515-522.

Wilson, Richard. 1946a. Aerial photo techniques. U.S. Forest Service. Techniques conf. Mimeo. 22pp.

__________. 1946b. Area classification-aerial photographic techniques. Proceedings of the Forest Survey Techniques meeting. Harvard Forest. May, 20-31. 22pp. (Lithographed).

__________. 1948. Photo interpretation aids for timber survey. Journal Forestry. 46: 41-44.

Wood, Kendall B. 1954. Forest engineering and photo interpretation. Photogram. Engineer. 20: 134-138.

Worley, David P. and Glenn H. Landis, 1954. The accuracy of height measurements with parallax instruments on 1:12,000 photographs. Photogram. Engineer. 20: 823-829.

__________, and H.A. Meyer. 1955. Measurements of crown diameter and crown cover and their accuracy for 1:12,000 photographs. Photogram. Engineer. 21: 372-375.

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APPENDIX A

Common and Scientific names of species

Common Name	Scientific Name
Douglas fir:	*Pesudotsuga menziesii Mirb.*
Western hemlock:	*Tsuga heterophylla (Raf.) Sarg.*
Western red cedar:	*Thuja plicata Donn.*
Western white pine	*Pinus monticola Dougl.*
Silver fir:	*Abies amabilis (Dougl.) Forbes.*
Cherry:	*Prunus emarginata (Dougl.) D.Dietr.*
Alder:	*Alnus rubra Bong. (Alnus oregona Nutt).*
Spruce:	*Picea glauca (Moench) Voss.*
Larch:	*Larix laricina (Du Roi) K.Koch.*

A. Statistical data of Table 3

(1) Regression No. 1 -- (V) on (Ht), (CW), (NT) and (V/T)

Item	(V)	(Ht)	(CW)	(CC)	(NT)	(V/T)
Means	81.93	118.27	22.87	81.20	166.00	55.87
Standard deviations	25.57	13.09	3.89	6.41	62.85	30.10
Correlation matrix	1.0000	0.5792 *	0.4036	0.3568	0.3320	0.4439
	0.5792	1.0000	0.4862	-0.1259	-0.4253	0.6548
	0.4036	0.4862	1.000	-0.1279	-0.3252	0.4215
	0.3568	-0.1259	-0.1279	1.000	0.8049	-0.4674
	0.3320	-0.4253	-0.3252	0.8049	1.0000	-0.5816
	0.4439	0.6548	0.4215	-.4674	-0.5816	1.0000
Covariance matrix	653.92	193.88	40.13	58.44	533.64	341.63
	193.88	171.35	24.75	-10.56	-349.93	257.97
	40.13	24.75	15.12	-3.19	-79.50	49.34
	58.44	-10.56	-3.19	41.03	324.07	-90.11
	533.64	-349.93	-79.50	324.07	3950.71	1100.21
	341.63	257.97	49.34	-90.11	-1100.21	905.84

Coefficients for the regression of the first on the remaining five variables

	1.0929	1.6002	-0.7312	0.4501	0.4527

Sum of squares removed by regression

	211.89	64.22	42.73	240.19	156.66

Multiple correlation coefficient 0.980 **

(2) Regression No. 2 ----- (V) on (Ht), (CW), and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	118.27	22.87	81.20
Standard deviations	25.57	13.09	3.89	6.41
Correlation matrix	1.0000	0.5792 *	0.4036	0.3568
	0.5792	1.0000	0.4862	-0.1259
	0.4036	0.4862	1.0000	-0.1279
	0.3568	-0.1259	-0.1279	1.0000
Covariance matrix	653.92	193.88	40.13	58.44
	193.88	171.35	24.75	-10.56
	40.13	24.75	15.12	-3.19
	58.44	-10.56	-3.19	41.03
Coefficients for the regression of the first on the remaining 3 variables		1.0531	1.3086	1.7970
Sum of squares removed by regression		204.18	52.51	105.02
Multiple correlation coefficient	0.744 *			

(3) Regression No. 3 ----- (V) on (Ht), (NT), and (V/T)

Item	(V)	(Ht)	(NT)	(V/T)
Means	81.93	118.27	166.00	55.87
Standard deviations	25.57	13.09	62.85	30.10
Correlation matrix	1.0000	0.5792 *	0.3320	0.4439
	0.5792	1.0000	-0.4253	0.6548
	0.3320	-0.4253	1.0000	-0.5816
	0.4439	0.6548	-0.5816	1.0000
Covariance matrix	653.92	193.88	533.64	341.63
	193.88	171.35	-349.93	257.97
	533.64	-349.93	3950.71	-1100.21
	341.63	257.97	-1100.21	905.84
Coefficients for the regression of the first on the remaining 3 variables	-	1.1283	0.3786	0.5157
Sum of squares removed by regression	-	218.75	202.04	176.18
Multiple correlation coefficient	0.955 *			

(4) Regression No. 4 ----- (V) on (Ht) and (CC)

Item	(V)	(Ht)	(CC)
Means	81.93	118.27	81.20
Standard Deviation	25.57	13.09	6.41
Correlation matrix	1.0000	0.5792 *	0.3568
	0.5792	1.0000	-0.1259
	0.3568	-0.1259	1.0000
Covariance matrix	653.92	193.88	58.44
	193.88	171.35	-10.56
	58.44	-10.56	41.03
Coefficients for the regression of the first on the remaining 2 variables	-	1.238	1.7432
Sum squares removed by regression	-	240.18	101.87
Multiple correlation coefficient	0.723 *		

(5) Regression No. 5 ----- (V) on (Ht), (CW), and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	131.40	24.80	81.20
Standard deviations	25.57	11.64	3.47	6.40
Correlation matrix	1.0000	0.8149 **	0.5692 *	0.3568
	0.8149	1.0000	0.5257	0.0851
	0.5692	0.5257	1.0000	-0.0495
	0.3568	0.0851	-0.0495	1.0000
Covariance matrix	653.92	242.60	50.49	58.44
	242.60	135.54	21.23	6.34
	50.49	21.23	12.03	-1.10
	58.44	6.34	-1.10	41.03
Coefficients for the regression of the first on the remaining 3 variables	-	1.4599	1.7345	1.2453
Sum of squares removed by regression		354.17	87.57	72.78
Multiple correlation coefficient		0.887 **		

(6) Regression No. 6 ----- (V) on (Ht) and (CW)

Item	(V)	(Ht)	(CW)
Means	81.93	131.40	24.80
Standard deviations	25.57	11.64	3.47
Correlation matrix	1.0000	0.8149 **	0.5692 *
	0.8149	1.0000	0.5257
	0.5692	0.5257	1.0000
Covariance matrix	242.60	135.54	21.23
	653.92	242.60	50.49
	50.49	21.23	12.03
Coefficients for the regression of the first on the remaining 2 variables	-	1.5651	1.4350
Sum of squares removed by regression	-	379.69	72.45
Multiple correlation coefficient	0.832 **		

B. Statistical data of table 4

(1) Regression No. 1 ----- (V) on (Ht), (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Meams	81.93	121.87	21.47	74.73
Standard deviations	25.57	12.69	1.88	6.52
Correlation matrix	1.0000	0.5988 *	0.3682	0.7390 **
	0.5988	1.0000	0.6868	0.5160
	0.3682	0.6868	1.0000	0.2725
	0.7390	0.5160	0.2725	1.0000
Covariance matrix	653.92	194.28	17.75	123.20
	194.28	160.98	16.42	42.68
	17.75	16.42	3.55	3.35
	123.20	42.68	3.35	42.52
Coefficients for the regression of the first on the remaining 3 variables	-	0.5829	0.1305	2.3034
Sum of squares removed by regression	-	113.25	2.32	283.78
Multiple correlation coefficient	0.781 *			

(2) Regression No. 2 ----- (V) on (Ht) and (CC)

Item	(V)	(Ht)	(CC)
Means	81.93	121.87	74.73
Standard deviations	25.57	12.69	6.52
	1.0000	0.5988 *	0.7390 **
Correlation matrix	0.5988	1.0000	0.5160
	0.7390	0.5160	1.0000
Covariance matrix	653.92	194.28	123.20
	194.28	160.98	42.68
	123.20	42.68	42.50
Coefficients for the regression of the first on the remaining 2 variables	-	0.5973	2.2992
Sum of squares removed by regression	-	116.04	283.26
Multiple correlation coefficient	0.781 **		

(3) Regression No. 3 ----- (V) on (Ht), (CW), and (CC)

	(V)	(Ht)	(CW)	(CC)
Means	81.93	120.73	19.87	75.20
Standard deviations	25.57	15.60	1.55	6.66
Correlation matrix	1.0000	0.6372 *	0.4496	0.8066 **
	0.6372	1.0000	0.6680	0.4456
	0.4496	0.6680	1.0000	0.2724
	0.8066	0.4456	0.2724	1.0000
Covariance matrix	653.92	254.20	17.85	137.30
	254.20	243.35	16.18	46.27
	17.85	16.18	2.41	2.81
	137.30	46.27	2.81	44.31
Coefficients for the regression of the first on the remaining 3 variables	-	0.4865	1.2052	2.5138
Sum of squares removed by regression	-	123.67	21.51	345.14

Multiple correlation coefficient 0.868 **

(4) Regression No. 4 ----- (V) on (Ht), (CW), (CC), and (NT)

Item	(V)	(Ht)	(CW)	(CC)	(NT)
Means	81.93	120.73	19.87	75.20	15.13
Standard deviations	25.57	15.60	1.55	6.66	2.92
Correlation matrix	1.0000	0.6372 *	0.4496	0.8066 **	0.3058
	0.6372	1.0000	0.6680	0.4456	-0.1072
	0.4496	0.6680	1.0000	0.2724	-0.1217
	0.8066	0.4456	0.2724	1.0000	0.6333
	0.3058	-0.1072	-0.1217	0.6333	1.0000
Covariance matrix	653.92	254.20	17.85	137.30	22.87
	254.20	243.35	16.18	46.27	-4.89
	17.85	16.18	2.41	2.81	-.55
	137.30	46.27	2.81	44.31	12.33
	22.87	-4.89	-.55	12.33	8.55
Coefficients for the regression of the first on the remaining 4 variables	-	0.3636	1.0635	3.0559	-1.4549
Sum of squares removed by	-	92.43	18.98	419.58	-33.27
Multiple correlation coefficient	0.872 **				

(5) Regression No. 5 ----- (V) on (Ht), (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	128.87	22.13	68.67
Standard deviation	25.57	8.95	1.68	7.90
Correlation matrix	1.0000	0.4175	0.4976	0.0650
	0.4175	1.0000	0.4181	-0.0684
	0.4976	0.4181	1.0000	-0.6299
	0.0650	-0.0684	-0.6299	1.0000
Covariance matrix	653.92	95.56	21.44	13.12
	95.56	80.12	6.30	-4.83
	21.44	6.30	2.84	-8.38
	13.12	-4.83	-8.38	62.38
Coefficients for the regression of the first on the remaining 3 variables	-	0.3266	12.4722	1.9113
Sums of squares removed by regression	-	31.21	267.40	25.08

Multiple correlation coefficient 0.704 *

(6) Regression No. 6 ----- (V) on (Ht) and (CC)

Item	(V)	(Ht)	(CC)
Means	81.93	128.87	22.13
Standard deviation	25.57	8.95	1.68
Correlation matrix	1.0000	0.4175	0.4976
	0.4175	1.0000	0.4181
	0.4976	0.4181	1.0000
Covariance matrix	653.92	95.56	21.44
	95.56	80.12	6.30
	21.44	6.30	2.84
Coefficients for the regression of the first on the remaining 2 variables	-	0.7250	5.9432
Sum of squares removed by regression	-	69.28	127.42
Multiple correlation coefficient		0.548 N.S.	

(7) Regression No. 7 ----- (V) on (Ht), (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	132.80	25.73	77.00
Standard deviation	25.57	9.56	2.25	7.27
Correlation matrix	1.0000	0.7497 **	0.4712	0.1737
	0.7497	1.0000	0.4456	-0.1378
	0.4712	0.4456	1.0000	-0.4234
	0.1737	-0.1378	-0.4234	1.0000
Covariance matrix	653.92	183.20	27.12	32.29
	183.20	91.31	9.59	-9.57
	27.12	9.59	5.07	-6.93
	37.29	-9.57	-6.93	52.86
Coefficients for the regression of the first on the remaining 3 variables	-	1.7317	4.0709	1.4580
Sum of squares removed by regression	-	317.25	110.40	47.08
Multiple correlation coefficient	0.852 **			

(8) Regression No. 8 ----- (V) on (Ht), (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	125.87	21.20	58.33
Standard deviations	25.57	14.23	3.10	14.47
Correlation matrix	1.0000	0.3660	-0.0512	-0.0148
	0.3660	1.0000	0.1723	-0.3444
	-0.0512	0.1723	1.0000	-0.4539
	-0.0148	-0.3444	-0.4539	1.0000
Covariance matrix	653.92	133.20	-4.06	-5.48
	133.20	202.55	7.60	-70.95
	-4.06	7.60	9.60	-20.36
	-5.48	-70.95	-20.36	209.52
Coefficients for the regression of the first on the remaining 3 variables	-	0.7384	-0.6705	0.1588
Sum of squares removed by regression	-	98.35	2.72	-0.87
Multiple correlation coefficient	$0.391^{N.S.}$			

(9) Regression No. 9 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	130.33	17.53	53.00
Standard deviations	25.57	26.70	3.09	18.50
Correlation matrix	1.0000	0.0782	-0.1730	-0.2474
	0.0782	1.0000	0.4678	-0.1678
	-0.1730	0.4678	1.0000	-0.3236
	0.2474	-0.1678	-0.3236	1.0000
Covariance matrix	653.92	53.38	-13.68	117.00
	53.38	712.67	38.60	-82.86
	-13.68	38.60	9.55	-18.50
	117.00	-82.86	-18.50	342.14
Coefficients for the regression of the first on the remaining 3 variables	-	0.1995	-1.6553	0.3008
Sum of squares removed by regression	-			

Multiple correlation coefficient 0.324 N.S.

C. Statistical data of table 5

(1) Regression No. 1 ----- (V) on (Ht), (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	114.33	21.40	74.87
Standard deviations	25.57	15.37	1.92	5.89
Correlation matrix	1.0000	0.3623	0.3439	0.6278 *
	0.3623	1.0000	0.7359	0.0794
	0.3439	0.7359	1.0000	-0.0834
	0.6278	0.0794	-0.0834	1.0000
Covariance matrix	653.92	142.38	16.89	94.56
	142.38	236.24	21.71	7.19
	16.89	21.71	3.69	-0.94
	94.56	7.19	-0.94	34.70
Coefficients for the regression of the first on the remaining 3 variables	-	0.0610	4.9503	2.8474
Sum of squares removed by regression	-	8.68	83.61	269.25
Multiple correlation coefficient	0.743 *			

(2) Regression No. 2 ----- (V) on (CW) and (CC)

Item	(V)	(CW)	(CC)
Means	81.93	21.40	74.87
Standard deviations	25.57	1.92	5.89
Correlation matrix	1.0000	0.3439	0.6278 *
	0.3439	1.0000	0.0834
	0.6278	-0.0834	1.0000
Covariance matrix	653.92	16.89	94.65
	16.89	3.69	-0.94
	94.65	-0.94	34.70
Coefficients for the regression of the first on the remaining 2 variables	-	5.3156	2.8700
Sum of squares removed by regression	-	89.78	271.39
Multiple correlation coefficient	0.743 **		

(3) Regression No. 3 ----- (V) on (Ht) (CW) (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	127.73	20.67	74.87
Standard deviations	25.57	14.62	1.80	5.15
Correlation matrix	1.0000	0.4662	0.4884	0.6168 *
	0.4662	1.0000	0.5287	0.1560
	0.4884	0.5287	1.0000	0.0103
	0.6168	0.1560	0.0103	1.0000
Covariance matrix	653.92	174.27	22.48	81.28
	174.27	213.64	13.90	11.75
		13.90	3.24	0.10
	81.28	11.75	0.10	26.55
Coefficients for the regression of the first on the remaining 3 variables	-	0.2906	5.6076	2.9123
Sum of squares removed by regression	-	50.64	126.06	236.71
Multiple correlation coefficient		0.795 **		

(4) Regression No. 4 ----- (V) on (Ht) (CW), (CC), (NT)

Item	(V)	(Ht)	(CW)	(CC)	(NT)
Means	81.93	127.73	20.67	74.87	13.27
Standard deviation	25.57	14.62	1.80	5.15	2.84
Correlation matrix	1.0000	0.4662	0.4884	0.6168 *	0.2137
	0.4662	1.0000	0.5287	0.1560	-0.2528
	0.4884	0.5287	1.0000	0.0103	-0.3587
	0.6168	0.1560	0.0103	1.0000	0.7152
	0.2137	-0.2528	-0.3587	0.7152	1.0000
Covariance matrix	653.92	174.27	22.48	81.28	15.52
	174.27	213.64	13.90	11.75	-10.50
	22.48	13.90	3.24	0.10	-1.83
	81.28	11.75	0.10	26.55	10.47
	15.52	-10.50	-1.83	10.47	8.07
Coefficients for the regression of the first on the remaining 4 variables	-	0.2597	5.3657	3.1822	-0.6477
Sum of squares removed by regression	-	45.26	120.62	258.65	-10.05
Multiple correlation coefficient	0.796 *				

(5) Regression No. 5 ----- (V) on (Ht), (CW), and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	119.80	23.73	71.67
Standard deviations	25.57	10.47	2.25	8.59
Correlation matrix	1.0000	0.3900	0.1883	0.0574
	0.3900	1.0000	0.4310	-0.0794
	0.1883	0.4310	1.0000	-0.3447
	0.0574	-0.0794	-0.3447	1.0000
Covariance matrix	653.92	104.41	10.84	12.62
	104.41	109.60	10.16	-7.14
	10.84	10.16	5.07	-6.67
	12.62	-7.14	-6.67	73.81
Coefficients for the regression of the first on the remaining 3 variables	-	0.9038	0.7573	0.3268
Sum of squares removed by regression	-	94.37	8.21	4.12
Multiple correlation coefficient	$0.404^{N.S.}$			

(6) Regression No. 6 ----- (V) on (Ht) and (CW)

Item	(V)	(Ht)	(CW)
Means	81.93	119.80	23.73
Standard deviations	25.57	10.47	2.25
Correlation matrix	1.0000	0.3900	0.1883
	0.3900	1.0000	0.4310
	0.1883	0.4310	1.0000
Covariance matrix	653.92	104.41	10.84
	104.41	109.60	10.16
	10.84	10.16	5.07
Coefficients for the regression of the first on the remaining 2 variables	-	0.9266	0.2816
Sum of squares removed by regression	-	96.75	3.05
Multiple correlation coefficient	$0.381^{N.S.}$		

(7) Regression No. 7 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(HT)	(CW)	(CC)
Means	81.93	126.07	27.00	78.00
Standard deviations	25.57	7.60	3.05	7.75
Correlation matrix	1.0000	0.7405 **	0.2099	-0.0783
	0.7405	1.0000	0.0216	-0.0036
	0.2099	0.0216	1.0000	-0.5598
	-0.0783	-0.0036	-0.5598 $\frac{1}{4}$	1.0000
Covariance matrix	653.92	143.93	16.36	-15.50
	143.93	57.78	0.50	-0.21
	16.36	0.50	9.29	-13.21
	-15.50	- 0.21	-13.21	60.00
Coefficients for the regression of the first on the remaining 3 variables	-	2.4756	1.8544	0.1589
Sums of squares removed by regression	-	356.31	30.34	-2.46
Multiple correlation coefficient	0.767 *			

D. Statistical data of table 6

(1) Regression No. 1 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	126.07	21.27	75.27
Standard deviations	25.57	13.37	2.09	6.86
Correlation matrix	1.0000	0.6416 *	0.5560 *	0.5180 *
	0.6416	1.0000	0.6472	0.5838
	0.5560	0.6472	1.0000	0.5137
	0.5180	0.5838	0.5137	1.0000
Covariance matrix	653.92	219.36	29.66	90.88
	219.36	178.78	18.05	53.55
	29.66	18.05	4.35	7.35
	90.88	53.55	7.35	47.07
Coefficients for the regressions of the first on the remaining 3 variables	-	0.7814	2.4647	.6567
Sum of squares removed by regression	-	171.41	73.10	59.68
Multiple correlation coefficient	0.682 N.S			

(2) Regression No. 2 ----- (V) on (Ht) and (CC)

Item	(V)	(Ht)	(CC)
Means	81.93	126.07	21.27
Standard deviation	25.57	13.37	2.09
Correlation matrix	1.0000	0.6416*	0.5560*
	0.6416	1.0000	0.6472
	0.5560	0.6472	1.0000
Covariance matrix	653.92	219.36	29.66
	219.36	178.78	18.05
	27.66	18.05	4.35
Coefficients for the regression of the first on the remaining 2 variables	-	0.9271	2.9696
Sum of squares removed by regression	-	203.37	88.08
Multiple correlation coefficient	0.682 *		

(3) Regression No. 3 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	126.73	17.87	75.20
Standard deviations	25.57	14.00	2.92	5.85
Correlation matrix	1.0000	0.5842 *	0.5921 *	0.7403 **
	0.5842	1.0000	0.7616	0.4529
	0.5921	0.7616	1.0000	0.4529
	0.7403	0.4529	0.4529	1.0000
Covariance matrix	653.92	209.12	44.28	110.66
	209.12	195.92	31.08	37.06
	44.28	31.18	8.55	7.74
	110.66	37.06	7.74	34.17
Coefficients for the regression of the first on the remaining 3 variables	-	0.3120	1.7792	2.4968
Sum of squares removed by regression	-	65.25	78.78	276.30

Multiple correlation coefficient 0.831 **

(4) Regression No. 4 ----- (V) on (Ht) (CW) (CC) and (NT)

Means	81.93	126.73	17.87	75.20	11.27
Standard deviations	25.57	14.00	2.92	5.85	2.55
Correlation matrix	1.0000	0.5842 *	0.5921 *	0.7403 **	0.1757
	0.5842	1.0000	0.7616	0.4529	-0.2221
	0.5921	0.7616	1.0000	0.4529	-0.2920
	0.7403	0.4529	0.4529	1.0000	0.5859
	0.1757	-0.2221	-0.2920	0.5859	1.0000
Covariance matrix	653.29	209.12	44.28	110.66	11.45
	209.12	195.92	31.18	37.06	-7.92
	44.28	31.18	8.55	7.74	-2.18
	110.66	37.06	7.74	34.17	8.73
	11.45	-7.92	-2.18	8.73	6.50
Coefficients for the regression of the first on the remaining 4 variables	-	0.2011	0.5993	3.5331	-2.5394
Sum of squares removed by regression	-	42.05	26.54	390.97	-29.08

Multiple correlation coefficient 0.811 *

(5) Regression No 5 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	123.00	24.47	71.67
Standard deviations	25.57	8.62	2.03	5.23
Correlation matrix	1.0000	0.1692	0.3610	-0.0418
	0.1692	1.0000	0.4571	-0.0871
	0.3610	0.4571	1.0000	-0.2465
	-0.0418	-0.0871	-0.2465	1.0000
Covariance matrix	653.92	37.29	18.75	-5.60
	37.29	74.29	8.00	-3.93
	18.75	8.00	4.12	-2.62
	-5.60	-3.93	-2.62	27.38
Coefficients for the regression of the first on the remaining 3 variables	-	0.0108	4.6808	0.2449
Sum of squares removed by regression	-	.40	87.77	-1.37
Multiple correlation coefficient		0.364 N.S.		

(6) Regression No 6 ----- (V) on (Ht) and (CW)

Item	(V)	(Ht)	(CW)
Means	81.93	123.00	24.47
Standard deviations	25.57	8.62	2.03
Correlation matrix	1.0000	0.1692	0.3610
	0.1692	1.0000	0.4571
	0.3610	0.4571	1.0000
Covariance matrix	653.92	37.29	18.75
	37.29	74.29	8.00
	18.75	8.00	4.12
Coefficients for the regression of the first on the remaining 2 variables	-	0.0156	4.5159
Sum of squares removed by regression	-	0.58	84.67
Multiple correlation coefficient	0.361 N.S.		

(7) Regression No 7. ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	81.93	129.93	27.27	78.00
Standard deviations	25.57	7.06	3.08	7.27
Coreelation matrix	1.0000	0.6706 *	0.5197 *	-0.1986
	0.6706	1.0000	0.1684	-0.2117
	0.5197	0.1684	1.0000	-0.6281
	-0.1986	-0.2117	-0.6281	1.0000
Covariance matrix	653.92	121.00	40.95	-36.93
	121.00	49.78	3.66	-10.86
	40.95	3.66	9.50	-14.07
	-36.93	-10.86	-14.07	52.86
Coefficients for the regression of the first on the remaining 3 variables	-	2.3022	5.1034	1.1328
Sum of squares removed by	-	278.57	208.98	-41.83

Multiple correlation coefficient 0.826 **

E Statistical data of table 7

(1) Regression No. 1 ----- (V) on (Ht) (CW) and (CC)

	(V)	(Ht)	(CW)	(CC)
Means	94.67	108.80	22.40	66.33
Standard deviations	26.52	16.84	5.38	12.17
Correlation matrix	1.0000	0.2440	-0.1991	0.9299 **
	0.2440	1.0000	0.3263	0.1181
	-0.1991	0.3263	1.0000	-0.3195
	0.9299	0.1181	-0.3195	1.0000
Covariance matrix	703.38	109.00	-28.43	300.12
	109.00	283.74	29.59	24.21
	-28.43	29.59	28.97	-20.93
	300.12	24.21	-20.93	148.10
Coefficients for the regression of the first on the remaining 3 variables	-	0.1773	0.3126	2.0417
Sum of squares removed by regression	-	19.33	-8.89	612.76

Multiple correlation coefficient 0.941 **

(2) Regression No. 2 ----- (V) on (Ht) (CW) and (CC)

	(V)	(Ht)	(CW)	(CC)
Means	94.67	85.27	18.68	84.67
Standard deviations	26.52	16.74	27.92	7.67
Correlation matrix	1.0000	0.6137 *	-0.4494	-0.5063 *
	0.6137	1.0000	-0.1224	-0.5389
	-0.4494	-0.1224	1.0000	-0.1388
	-0.5063	-0.5389	-0.1388	1.0000
Covariance matrix	703.38	272.52	-332.79	-102.98
	272.52	280.35	-57.23	-69.19
	-332.79	-57.23	779.74	-29.71
	-102.98	-69.19	-29.71	58.81
Coefficients for the regression of the first on the remaining 3 variables	-	0.5589	-4.3580	-1.3137
Sum of squares removed by regression	-	152.31	145.03	135.28

Multiple correlation coefficient 0.784 *

(3) Regression No. 3 ----- (V) on (Vt) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	94.67	84.20	12.87	81.00
Standard deviation	26.52	24.47	2.70	8.28
Correlation matrix	1.0000	-0.4457	0.0183	-0.0163
	-0.4457	1.0000	0.1445	-0.3166
	0.0183	0.1445	1.0000	-0.4096
	-0.0163	-0.3166	-0.4096	1.0000
Covariance matrix	703.38	-289.21	1.31	-3.57
	-289.21	598.74	9.53	-64.14
	1.31	9.53	7.27	-0.14
	-3.57	-64.14	-9.14	68.57
Coefficients for the regression of the first on the remaining 3 variables	-	-0.5434	0.2255	-0.5304
Sum of squares removed by regression	-	157.17	0.30	1.89
Multiple correlation coefficient	$0.476^{N.S.}$			

F Statistical data of table 9

(1) Regression No. 1 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	48.02	98.51	21.14	72.08
Standard deviations	24.28	22.94	4.38	12.52
Correlation matrix	1.0000	0.3610 **	0.3242 **	0 .1859
	0.3610	1.0000	0.6052	-0.0929
	0.3242	0.6052	1.0000	-0.1156
	0.1859	-0.0929	-0.1156	1.0000
Covariance matrix	589.61	201.07	34.39	56.52
	201.07	526.18	60.55	-26.68
	34.39	60.65	19.09	-6.33
	56.52	-26.68	-6.33	156.75
Coefficients for the regression of the first on the remaining 3 variables	-	0.2842	1.0485	0.4512
Sum of squares removed by regression	-	57.14	36.06	25.50
Multiple correlation coefficient	0.499 **			

(2) Regression No. 2 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	48.02	96.64	20.96	76.49
Standard deviations	24.28	22.12	4.17	12.17
Correlation matrix	1.0000	0.3688 **	0.1929	0.2655
	0.3688	1.0000	0.4553	0.1032
	0.1929	0.4553	1.0000	-0.1332
	0.2655	0.1032	-0.1332	1.0000
Covariance matrix	589.61	198.10	19.52	78.46
	198.10	489.36	41.96	27.77
	19.52	41.96	17.36	-6.75
	78.46	27.77	-6.75	148.06
Coefficients for the regression of the first on the remaining 3 variables	-	0.3333	0.5096	0.4906
Sum of squares removed by regression	-	66.03	9.95	38.49

Multiple correlation coefficient 0.441 **

(3) Regression No 3 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	58.27	103.25	22.30	71.00
Standard deviations	23.88	29.16	4.41	9.35
Correlation matrix	1.0000	0.2418 N.S.	0.1141 N.S.	0.1635 N.S.
	0.2418	1.0000	0.7821	-0.3226
	0.1141	0.7821	1.0000	-0.3277
	0.1635	-0.3226	-0.3277	1.0000
Covariance matrix	570.15	168.34	12.02	36.51
	168.34	850.29	100.56	-87.95
	12.02	100.56	19.45	-13.51
	36.51	-87.95	-13.51	87.44
Coefficients for the regression of the first on the remaining 3 variables	-	0.3575	-0.7740	0.6576
Sum of squares removed by regression	-	60.18	9.30	24.01
Multiple correlation coefficient	0.405 N.S.			

(4) Regression No. 4 ----- (V) on (Ht) (CW) and (CC)

Item	(V)	(Ht)	(CW)	(CC)
Means	58.27	97.60	19.97	74.57
Standard deviations	23.88	19.32	4.52	3.84
Correlation matrix	1.0000	-0.1663	-0.2209	0.5831 **
	-0.1663	1.0000	0.5850	-0.0387
	-0.2209	0.5850	1.0000	-0.1101
	0.5831	-0.0387	-0.1101	1.0000
Covariance matrix	570.15	-76.71	-23.84	53.40
	-76.71	373.22	51.09	-2.87
	-23.84	51.09	2044	-1.91
	53.40	-2.87	-1.91	14.71
Coefficients for the regression of the first on the remaining 3 variables	-	-0.0971	-0.5938	3.5338
Sum of squares removed by regression	-	7.45	14.17	188.70
Multiple correlation coefficient	0.607 **			