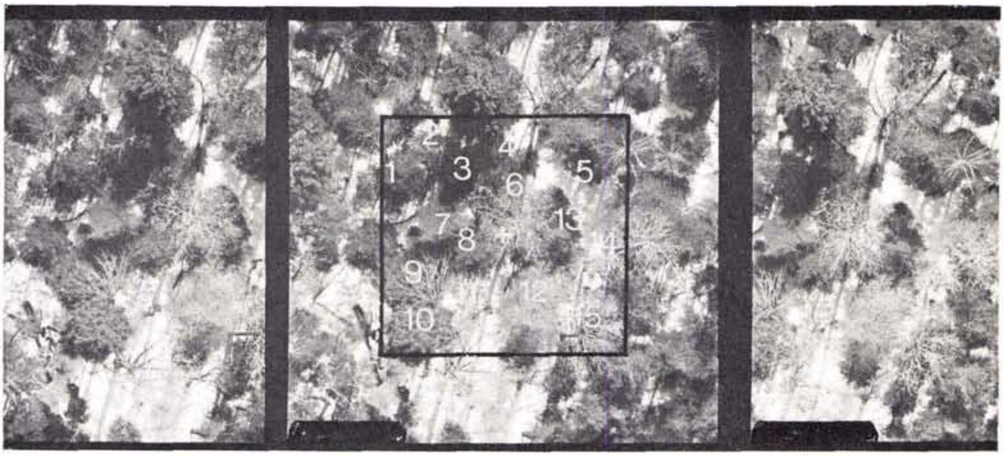

FIG. 1. The procedure for using large-scale photography in forest inventories. (See also Table 1).

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Tree Size from Large-Scale Photos

Height, crown area, diameter and volume are derived from 1:1,000-scale pictures.

(*Abstract on next page*)

FIVE YEARS AGO we reported in this Journal (Sayn-Wittgenstein and Aldred, 1967) on preliminary results of experiments of volume estimation of individual trees from measurements made on large-scale aerial photographs. Since that time, a number of further studies have been completed on the estimation of both volumes and diameters; the results have been summarized in a report which has just been issued by the Forest Management Institute (Aldred and Sayn-Wittgenstein, 1972). As there is a direct connection with the first article, we shall briefly summarize the main findings.

The basic approach was to photograph sample locations in the forest at scales in the vicinity of 1:1,000. Sample plots were established on the photos (Figure 1) and all trees on the plot larger than a specified size were numbered, identified as to species, and measured. The measurements were used in regression equations to estimate individual tree volumes which were summed to yield estimates of plot volume (Table 1). Diameter statistics are derived from a similar procedure. The variables measured on the photos are tree height, crown area and "expressions of relationship to neighboring trees." The latter category includes potentially a large number of variables such as distance to the nearest neighbor, expressions of the growing space available to the tree, and expressions of the relationship of the tree's size to the size of its neighbors.

The recently completed studies include tree data from many locations and species in eastern Canada. Analysis involved, first, a screening of data using stepwise regression to select the most promising variables and models and, next, the testing of these preliminary models with new data. A large number of independent variables were tested, including those mentioned in the 1967 article. Surprisingly enough, the independent variables that proved most successful as estimators of volume were also best for the diameter-estimating equation. The most useful equation was:

$$\hat{Y} = a + b(H) + c[H\sqrt{(CA)}] + d[\sqrt{(CA)}]$$

where $\hat{Y}$ is estimated tree diameter (or volume), H is tree height, CA is crown area, and a, b, c, d are least-squares regression coefficients. Separate equations were determined for different species and species groups. The above model was not optimal for all applications. This is not a radically new equation, and similar models have been proposed by other authors (Dilworth, 1956; Bonnor, 1968). A few other models appear worthy of further consideration. There was, however, little further evidence that the "measures of relations to neighboring trees" were useful, although they did occasionally emerge as significant variables. Other findings included:

- The possibility of using oblique photographs for direct diameter measurement was again reviewed. The method is rarely useful, and then only for trees at the edge of clearings, or in the open. In addition to the visibility problem, there are serious photogrammetric and computational difficulties.
- The estimation of tree diameters by photo measurement of tree shadows is definitely not recommended. Halation, slope and other factors introduce inaccuracy.
- *Crown area* was a more reliably measured and more useful variable than *crown radius* and *crown diameter*. In general, because of a complete lack of standardization of crown measurement from aerial photographs, comparison of results from different authors is most difficult.
- Nelder (1966) has suggested that inverse polynomials may be the most appropriate models for expressing certain responses of plants to their environments. For example, they could correctly depict the relationship between tree diameter and increasing growing space: the curve at first rises with growing space, then levels off, reaches a maximum value, and then, possibly begins to decline, The arguments are theoretically convincing, but in analyzing the data we found no evidence for the superiority of inverse polynomials over the usual unbounded expressions.
- Several investigations of volume-estimation equations have relied on individual tree volumes derived from diameter measurements and volume tables. This violates the theory of regression estimation. The volume data used in constructing equations should be derived from ground measurements of the individual trees involved, and should not be estimates; otherwise, equations will produce deceptively accurate results.
- The report also includes trials and recommendations of the efficiency of different dot grids for the estimation of crown areas. A density of about 17 dots per crown seemed optimal considering accuracy and measurement time. These findings are perhaps already superseded by another report (Brun, 1972): the Forest Management Institute has assembled a system linking a stereotope and a digitizer (Figure 2). X, Y and Z coordinotes of individual trees are entered directly on cards or tape and there is an automatic progression from these measurements to final inventory statistics (Figure 1). Crown area is not measured with a dot grid, but is calculated from the coordinates of points along the crown perimeter. The gain in efficiency has been considerable.

ABSTRACT: *The problem of measuring tree height, crown area and other variables on large-scale photos and using them in regression models to estimate tree diameter and volume is discussed. Recommendations on the most useful tree variables, regression models and photo measurement procedures are included. Efforts to increase the speed and accuracy of the photo measurements by coupling a stereotope, digitizer and card punch, in preparation for computer processing, have proved successful.*

TABLE 1. THE PROCEDURE FOR USING LARGE-SCALE PHOTOGRAPHS IN FOREST INVENTORIES. (SEE FIGURE 1).

Photogrammetric parameters. Record flying altitude, A, absolute parallax, P, and lens focal length, F.

Tree interpretation and measurement. Identify species, sp, and measure and record differential parallax, dp, and crown area, ca, of the tree images on the plot.

Calculations. Using an appropriate mathematical function, f_i, and the data recorded above, calculate:

1. Tree height, $H=f_1, (A, P, dp)$
2. Crown area, $CA=f_2, (A, F, ca)$
3. Diameter, $D=f_3\ (sp, H, CA)$
4. Volume, $V=f_4\ (sp, H, CA)$.

Checks. Use a check procedure to detect obvious errors and suspicious values.

Results. Tabulate forest inventory data such as estimates of average basal area and volume per acre and the stand and stock tables.

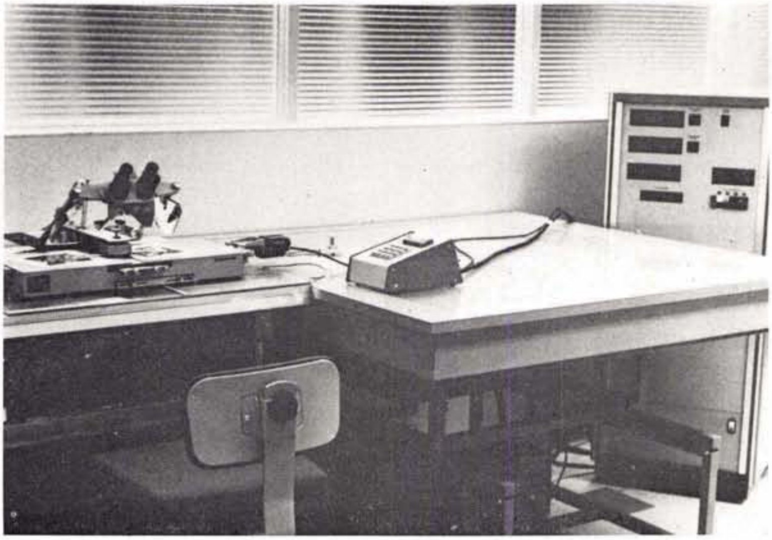

FIG. 2. A stereotope digitizer attached to a card punch for recording photo measurements (from Brun, 1972).

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