PHOTO INTERPRETATION IN FOREST INVENTORIES*

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MOST photogrammetrists know how important aerial photos are in preparing maps, but few of them realize how much the popularity of this method is due to its early use on forest inventories.

Foresters make forest inventories to find the location and area of timber, its volume, species, size, and condition. They use this information in managing, purchasing, or selling forest properties. Since forests are usually located in wild and relatively inaccessible areas where ground surveys are expensive, some use of aerial photos has been advocated for many years. Today many forest inventories start with flying and interpreting aerial photos.

Inventories in which every tree on the area must be measured are rare in America;[1] sampling is the rule. As in most forms of sampling, the universe must first be stratified—that is, broken down into groups or classes. This can be done most efficiently by mapping or classifying the forest on aerial photos.

But before going into detail on classifying forest areas on aerial photos, the history of this phase of photo interpretation should be briefly traced.

History of Photo Interpretation in Forest Inventories

Because mapping from aerial photos requires some photo interpretation and as photogrammetry is used in both, it is impossible to trace the growth of one without mentioning the other. Publications of the past 30 years show the growing importance of photo interpretation in the specialized field of forest inventories.

Although publications prior to the first World War do not mention aerial photos, in 1919 a Lt. Lewis suggested in the *Canadian Forestry Journal* that aerial photos be used in mapping inaccessible forest areas and ventured the idea that carefully analyzed stereograms could be used as standards for photo interpretation on such inventories.

The great acreage of inaccessible forest land in Canada stimulated Canadian interest in aerial mapping and in the early 1920's many articles in Canadian forest magazines reported this novel use of aerial photos by various pulp and paper companies. Articles dealt primarily with preparing mosaics and stressed the ease with which commercial forest areas and old burns are recognized. Mapping by photos versus sketching from a plane was also discussed. L. A. Andrews writing in *Canadian Forestry Magazine* concluded that estimates of damage and distribution of species would be needed before aerial cruising became accurate. Unfortunately, after 30 years the research needed to assemble the essential data is still incomplete and the information is unavailable to aerial estimators.

In the late 1920's Elwood Wilson reported to the International Silvicultural Congress that identification of species, height measurements, forest type classification, and even volume estimates were possible on aerial photos by means of stereo-interpretation.

In the early 1930's articles became more specific as to interpretative techniques and emphasized the advantage of stereo study over the use of a single

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[1] They have been used extensively in some European forests under intensive management and are used occasionally on small tracts in America.

photo or a mosaic. Earlier procedures for estimating board- or cubic-foot volume mentioned a count of tree crowns on photos multiplied by the volume in an individual tree determined from field measurements. Some articles now suggested not only a count of trees but height measurements on photos using the shadow method. H. E. Seely, in several articles throughout this period, discussed classifying forest areas on both vertical and oblique photos using species, height, and age classes.

During the 30's, forest inventories were started in Alaska, the Rocky Mountain Region, and in California by the U. S. Forest Service using available aerial photos. Extremely detailed procedures for field classification based upon form, relative size, and appearance of vegetation were worked out and improvements in mapping procedures and equipment were developed. The use of aerial photos in forest inventories spread rapidly in the United States after the Department of Agriculture began its standard 1:20,000 scale photo program in the late 30's. Articles at this time discussed tree height measurements by parallax, and studies made in Germany and other European countries considered the accuracy of photo versus field measurements. Forest inventories started by Japan in Manchuria and by other countries in the Far East used aerial photos.

During the early 1940's great emphasis was placed on photo interpretation by the armed forces, and many foresters both in America and abroad were first introduced to the use of aerial photos at military intelligence schools. After the war these same foresters, skilled in interpreting vegetation and other terrain conditions, found in forest inventories the opportunity to capitalize on both their civil and military experience.

And so from 1946 on the literature is filled with discussions of the technique of forest classification; the use of both infrared and panchromatic photos of varying scale; the technique of simple photogrammetric measurements of height, crown width, and crown coverage; the correlation of all of these with ground measurements, and the development of aerial volume tables.

As statistical methods were accepted by foresters and sampling became a tool in forest inventories, some foresters recognized that complete mapping of the forest may not be a necessary step in securing timber volume. Instead, detailed photo interpretation of a number of sample plots and the field examination of a few of the same plots is now believed by many to be the most efficient form of forest inventory; particularly in areas of low relief.

Interpretation Techniques Used in Forest Inventories

The technique of these interpretations, whether the forest is to be sampled or completely mapped, falls logically under the headings of (1) classification into relatively homogeneous areas, (2) measurement of these areas, and (3) determination of per-acre volume.

CLASSIFICATION

Forests are classified into like areas by qualitative interpretation helped out by an occasional photo measurement. The photos are viewed under lens stereoscope and the classes identified by the tone, texture, shape, and relative size of forest areas and individual trees. Shadows are studied as well as tree images because they often indicate species, condition, or the size of the trees.

The usual classifications fall into four general groups: (1) forest types, based upon species; (2) forest sites, based upon topographic and soil condition; (3) forest stand size, based upon diameter and height of the trees; (4) forest condition, based upon past treatment of the forest.

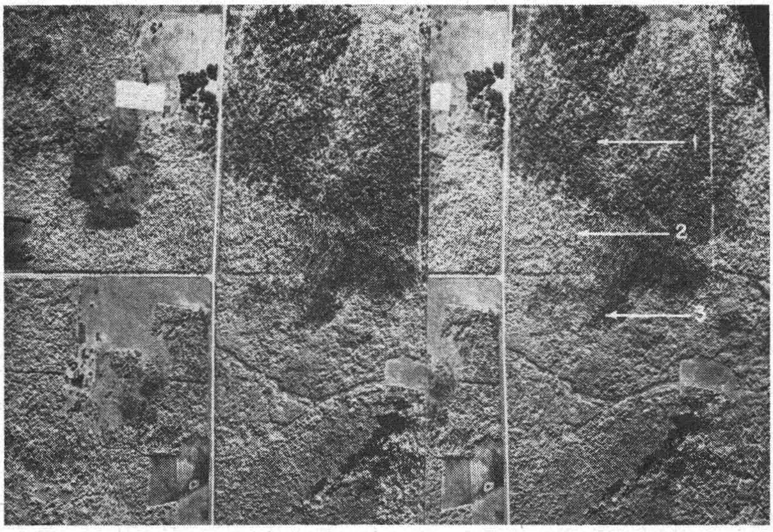

FIG. 1. Differences in tone on modified infrared photographs indicate different forest types. (1) Mixed hardwood swamp, (2) aspen birch upland, and (3) cutover conifer swamp. Original photo 1: 15,840, Chippewa National Forest.

Forest types.—Foresters skilled in classifying forest types by means of key species on ground inventories naturally tried first to recognize these same species on aerial photos. They tried to rely on the tone of the photo and were somewhat baffled when differences clearly visible on the ground, such as between dark conifer and much lighter hardwood foliage, were not always distinguishable on aerial photos. They soon found that uniform stands of timber register many different tones and that the direction of light, the size and density of the foliage, and the resulting shadows had far more effect than mere differences in color so apparent on the ground.

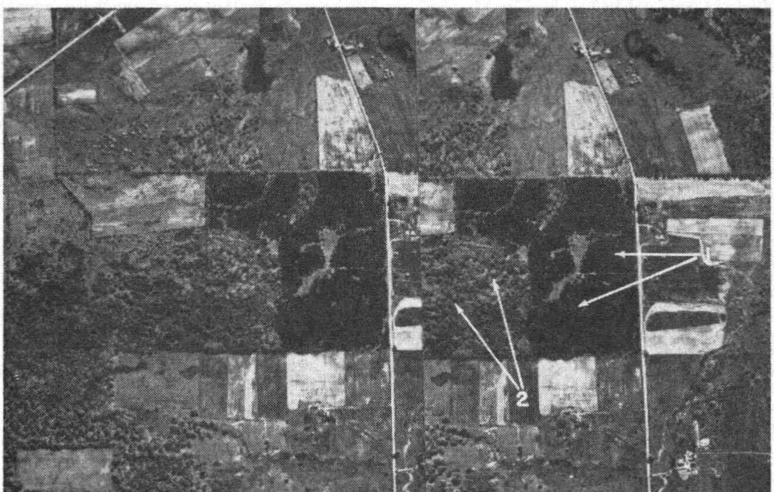

FIG. 2. Differences in tone found on standard panchromatic photographs taken in spring or fall also indicate different forest types. (1) Plantation with two species of conifer, (2) natural hardwood stand with at least two species of mature trees. Original photo 1:20,000, U. S. Department of Agriculture, Forest Survey, Ohio.

During the war infrared film was used in detecting camouflage, particularly dead vegetation. It was natural that foresters should try this film as a means of recognizing forest species. A modified infrared film (Figure 1) has been used to separate conifer and hardwood species particularly in the Northeast and Lake States areas of this country. But even this has serious deficiencies and sometimes indicates identical tone for worthless dead vegetation, wet swamp, and valuable stands of young conifers.

At present some foresters are enthusiastic about color film and see in color transparencies a means of recognizing species, provided the film can be reduced in cost, and practical means devised for using the transparencies outside the laboratory. However, the same differences in tone due to direction of the sun and shadow are present in color as in panchromatic or infrared film and may prove equally baffling to the interpreter. In fact we find that in areas of low relief, panchromatic film (Figure 2) flown in spring when hardwood foliage is new or in the fall when foliage is turning, will give tonal

FIG. 3. Stereogram illustrating correlation between forest and soil types. (1) Upland soil supports one forest type, (2) bottomland soil supports a different forest type, and (3) soil scientists type line indicated by difference in photographic tone of the bare ground coincides exactly with the foresters' type line indicated by the difference in tone of the forest cover.

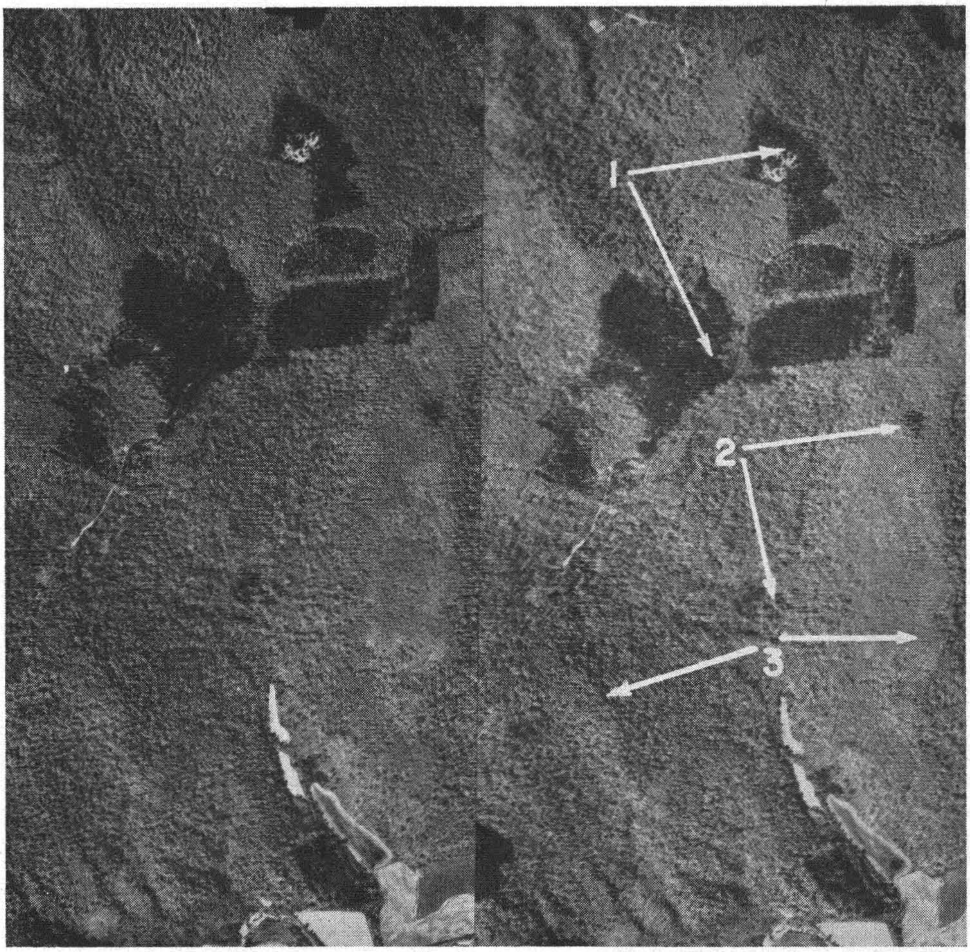

FIG. 4. Stereogram illustrating changes in forest due to past treatment. (1) Conifers originating on abandoned fields, (2) conifers originating on natural openings in the forest, and (3) original hardwood forest on north (moist) and south (dry) slopes. Original panchromatic photo 1:20,000, U. S. Department of Agriculture.

variations as valuable to the forester as other, more complicated photography.

A few species can be identified by means other than the tone of photos. The umbrella-like shape of the elm and the needle points of some conifers cast easily recognized shadows. White pine and aspen-birch may be separated by noting relative sizes, and some conifers may be recognized by the even photo texture of their small crowns in contrast with more coarse texture of the hardwoods. However, since it is not possible for the interpreter to identify all species on photos, he may have to approach the problem indirectly through forest sites.

Forest sites.—Under stereo even minor topographic differences are accentuated on aerial photos. Geologists and soil scientists have long recognized that these topographic differences are good indicators of basic soil conditions. Since forest types, as well as size, quality, and rate of growth, are correlated with soil and topography (Figure 3) interpreters can often use forest sites based on topography to classify forest areas.

Stand size.—This classification, based upon the size of the timber, requires some photo measurements. Texture and relative height of photo images may be used, but most foresters rely on the quantitative measurements of total height, crown diameter, and crown coverage, or, to some extent, tree counts to identify stand-size classes. These measurable factors have been found to correlate fairly well with such field criteria as height, diameter, number of trees, and volume.

Condition.—The treatment a forest stand receives may cause differences in species composition and in the quality and size of timber. One of the first classifications used by foresters on aerial photos was based on the condition of the forest. Forest fires, logging, and clearing all made characteristic patterns and changes in the normal photographic texture and tone of the forest (Figure 4). Furthermore, these differences in texture and tone were visible on photos flown many years after the change in forest condition occurred. Since species and size class are often correlated with these old burns or slashings, the forest can be stratified by condition.

Rarely do foresters use only one means of classification in their forest inventories. Instead, most classification schemes recognize species, stand-size condition, and often site or age class. These schemes vary greatly according to the region, the character of the forest, and the type of inventory for which they were developed. In their attempt to adapt these involved schemes for use on aerial photos, foresters have produced many complicated photo-classification systems. In most of these schemes final interpretation must be completed in the field, since many classes are not recognizable on the available photos.

As a result of this procedure the belief has spread that photo interpretation of forest conditions must be done in the field, and that interpreters can only be trained by work on field crews. Some field experience is necessary but if the classification scheme is simple and the classes used can be recognized on photos, an interpreter can be trained by means of carefully analyzed stereograms and previously recorded field data. A few hours spent comparing his interpretations with these standards may have as much training value as a number of days spent as a member of a field crew.

Foresters have recognized in aerial photos a means of reducing the cost of their forest inventories. But they must learn to simplify their methods of forest classification if they are to make the most efficient use of the aerial photos.

MEASUREMENT OF FOREST AREAS

In forest inventories the area within each classification is of prime importance. Traditionally these areas have been sketched on a map, then measured by planimetring or some similar method.

Mapping procedure.—In this paper aerial mapping will not be discussed. However, most forest inventories do use a mapping procedure. Classifications are identified under stereo and outlined within the net area of contact prints. Only the more obvious classes are identified in the office. Then the contact prints are taken to the field where the more obscure classes are identified and outlined. Annotated prints are then sent to a central office for compilation by standard photogrammetric methods. Details of both field mapping and compilation have been published in PHOTOGRAMMETRIC ENGINEERING and several other publications. Areas are usually measured on the completed maps.

FIG. 5. Transparent templet oriented over each contact print marks the plots to be classified. Only a fraction of the total area is actually classified, but the resulting data will meet the standard of accuracy for most forest surveys, and can be secured far cheaper than by normal mapping procedures.

Sampling procedure.—A simpler, faster, and less expensive method of measuring forest areas has been developed. It makes use of sampling procedures and statistical methods. A transparent templet (Figure 5) with a number of sample plots evenly distributed over an area equal to the net area of the aerial photos used, is oriented over each contact print that is within the tract to be measured.

Each plot is examined under stereo and classified according to the prescribed scheme. If 20 per cent of the sample plots are in a given class, it is assumed that 20 per cent of the total area is in that class. By applying proportions obtained in this way to an accurately computed tract acreage, the area in each classification can be obtained. Accuracy of course depends largely upon the number of sample plots classified.

Photo interpreters find the procedure easy to learn and use because they can concentrate their efforts on plots small enough to fall into a single class. Although only a fraction of the total area is actually classified, the method generally results in inventories as accurate as and cheaper than those obtained by normal mapping procedures.

DETERMINATION OF PER-ACRE VOLUME

Few forest inventories rely on volume estimates made directly from aerial photos. Although this has been the dream of some foresters and photogrammetrists for nearly 30 years and has been the object of considerable study, most inventory procedures use per-acre volumes computed from field plots.

Field volumes.—Field plots of known area are selected from mapped areas or from plots classified on photos. Field parties visit each plot and make precise measurements of the trees. From these measurements, volumes are computed and the per-acre average for each classification is determined. The number of plots needed for a given statistical accuracy can be estimated in advance of the field work and their distribution can be determined from the previous photo classification. It is this control of the field work which many foresters consider the most important contribution of photo interpretation to forest inventories.

Although this selection of field samples by photo study is undoubtedly a great advance over previous ground inventory methods, the emphasis, other than in classification and mapping, is still on field procedures. The average volumes are determined by field measurements, and the number of field plots cannot be reduced below that needed to get reliable field volumes. Furthermore, in remote and inaccessible areas where it would cost too much to take field plots the method will not work. True aerial estimating requires a technique of quantitative interpretation which will give average volumes directly from measurements made on the aerial photos alone.

Photo volumes.—Per-acre volumes have been estimated directly from aerial photos by (1) comparing the plots to be estimated with representative stereograms whose per-acre volumes are known and (2) by measuring tree or stand images and using an aerial volume table.

The comparison with representative stereograms showing plots of known volume makes use of the ability of the interpreter to recognize and compare minute likes or differences, even though he may not be able to measure them. Although used successfully on a few estimates, this procedure is weak in that the volume measured on the specific plots for which stereograms are made is seldom an average for the class, and the infinite variation in forest conditions may require a large number of stereograms. Furthermore, differences in specifications (focal length of the camera, flying height, or photo base) between the photos studied and those used in preparing the stereograms will cause like stands to appear radically different to the interpreter.

Aerial volume tables both for the individual tree and for the entire stand have been developed and show great promise (Table 1). In general these tables correlate average gross[2] board or cubic volumes obtained from field measurements with measurable photo factors of total height, crown diameter, and crown coverage or number of trees. Occasionally photo measurements have been correlated with tree measurements made on the ground and the final table worked out from forest yield tables.

Tree tables correlate individual tree gross volume with photo measurements of total height and crown diameter. Since the desired per-acre volume is a product of the tabular volume and a tree count, they are most usable in scattered stands of mature trees and on large scale photos. In dense stands or on small scale photos where tree counts are slow and very inaccurate, tree tables are impractical.

[2] Gross volume—the total board- or cubic-foot volume of the tree or stand without deductions for rot, poor form, or other cull.

Stand volume tables correlating per-acre gross volume from field measurements with photo measurements of average total height, crown diameter, and crown coverage can be used on small and medium scale photos. The three measurements per plot take little time, and since the tabular volumes are already averages of several plots, these tables are the most direct approach to the required per-acre volume.

TABLE 1

AERIAL VOLUME TABLES

Tree Volume Table*							Stand Volume Table† (10–14 Ft. Crown Diameter)					
Visible Crown Diameter	Total Height (Feet)						Average Stand Height	Crown Cover (Per Cent)				
	20	30	40	50	60	70		15	35	55	75	95
Feet	*Cubic Feet*						*Feet*	*Cubic feet per acre*				
10	2.2	3.2	4.6	7.1	11.0	—	20	250	400	450	500	650
11	2.8	3.8	5.5	8.3	12.2	—	30	300	450	500	550	750
12	3.4	4.5	6.7	9.5	13.6	21.2	40	350	500	600	650	850
13	—	5.5	8.0	10.7	15.1	22.9	50	400	550	700	750	1,000
14	—	6.7	9.3	12.1	16.6	24.7	60	550	800	950	1,050	1,300
							70	900	1,250	1,400	1,500	1,700

* Tree volume tables give average volume for individual trees of given measurements. Volume must be converted to per acre figure by count of trees on the acre.

† Stand volume tables give average per acre volume for stands of given measurements and crown cover. Desired per acre figure is read directly from table.

The use of either type of table requires some elementary photogrammetry. In some areas[3] tree or stand heights are determined by shadow measurements. The most generally usable system, however, seems to be by parallax measurements. Although simple parallax bars to be used with lens stereoscopes are available at low cost, the most practical measuring device seems to be the parallax wedge (Figure 6). The cost is but a fraction of that for other portable height finders, there are no moving parts to get out of adjustment, and the accuracy obtained by trained operators on simple parallax difference measurements seems to be identical with that obtained by far more expensive instruments.

Crown diameters are measured with a wedge or a dot type crown diameter scale, consisting of a series of small dots of graduated diameter. These simple devices are usually printed on film. Micrometer attachments for lens stereoscopes have been designed for such horizontal measurements, but they are more complicated, more expensive, and less usable than the crown scales.

The proportion of the acre covered by tree crowns is measured by comparison with a crown coverage scale. This device consists of a graduated series of squares with randomly selected black dots covering 5 to 95 per cent of their surface. All these comparative measurements are made under stereoscope in order to reduce the effect of shadows.

As he studies the plot under his stereoscope, the interpreter makes what he considers average readings of the three factors for that plot. He converts these readings to measurements in ground units by means of a slide rule or

[3] Canada, for example, where long shadows are common and oblique photos are frequently advocated for forest inventory.

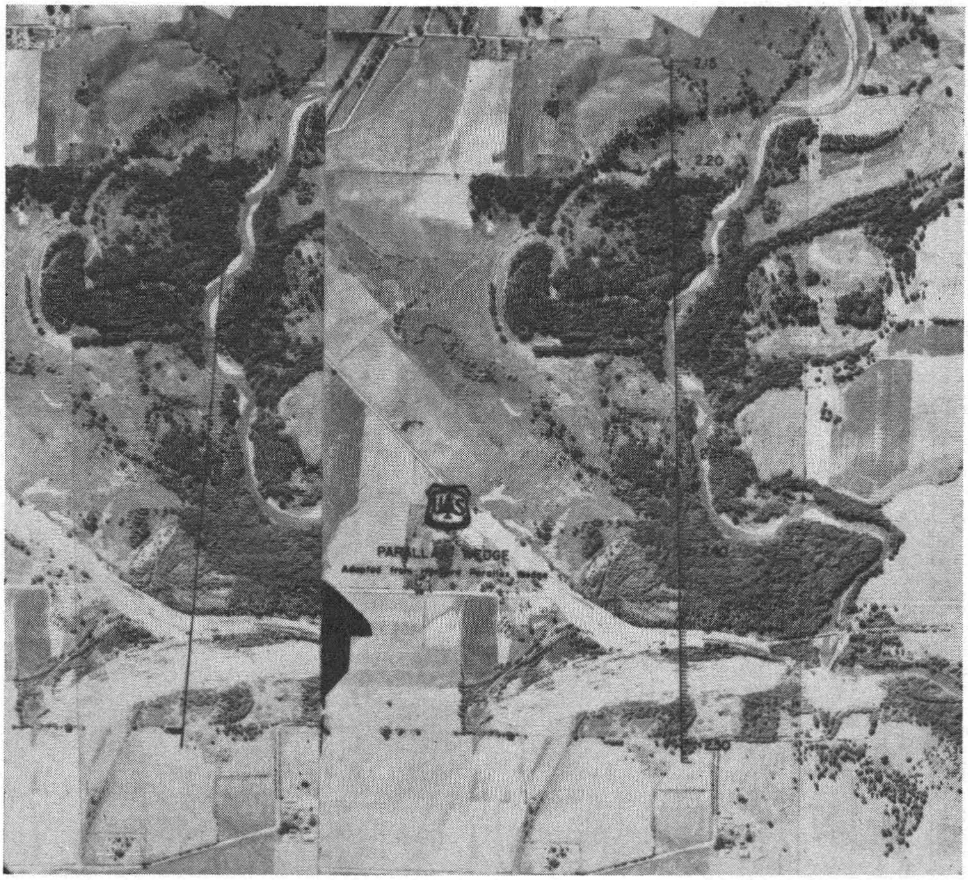

FIG. 6. Stereogram illustrating use of parallax wedge to measure tree heights. Variation between height measurements made on 1:20,000 photos and height measurements made by Abney level on the field averages less than 6 feet when parallax wedge technique is used.

simple conversion tables. He then reads average per-acre volume for these measurements from his aerial volume table and records both readings and volume for each plot. Using this procedure an experienced interpreter can classify and estimate volume on at least 50 one-acre plots per day.

For individual trees, total height and other measurements are more accurate on large scale photos. But the forester must consider stands rather than individuals. Because of stand variability within the acre plot, the average measurements used in this technique are about as good on the 1:15,000 or 1:20,000 scale photos normally flown for forest inventory as they would be on the larger, more costly scales. Furthermore, experienced interpreters using reliable aerial volume tables can estimate over-all gross volumes which will not vary significantly from those measured on the ground (Table 2).

Gross volumes are used since the interpreter cannot recognize the defects on which cull deductions are based and these deductions may vary considerably between stands. However, many foresters consider the calculation of cull percents to be a weak point in most forest inventories, even those made on the ground. Research may give us equally accurate methods for use on photos.

An equally important problem is the requirement on most forest inventories that volumes be determined by species and diameter class. Since the interpreter cannot recognize all species, and because he cannot directly measure diameter, he can only get these details from field plots. The most practical procedure consists of adjusting his over-all volumes from gross to net by percentages from a few plots measured both on the photos and in the field. From the same plots he can secure percentages which can be used to distribute his adjusted over-all volume by species and diameter classes. Studies indicate that the number of expensive field plots needed for such a procedure would be considerably less than are now taken on most forest inventories.

TABLE 2

COMPARISON PHOTO AND FIELD OVER-ALL VOLUME ESTIMATES FROM SURVEYS MADE IN THE CENTRAL STATES

	Photo Estimates			*Field Estimates*		
Size of Tract	Mean per-Acre Volume	Size of Sample	Cost	Mean per-Acre Volume	Size of Sample	Cost
Acres	*Bd. ft.*	*Plots*	*Man days*	*Bd. ft.*	*Plots*	*Man days*
40	6,537±207	35 1-acre	1	6,241±628	35 $\frac{1}{5}$-acre	4
640	2,720±180	56 1-acre	1	2,660± 53	640 $\frac{1}{5}$-acre	20
25,000	1,230± 86	370 1-acre	18	1,500±300	86 $\frac{1}{5}$-acre	100
100,000	5,251±391	37 1-acre	1	4,973±515	37 $\frac{1}{5}$-acre	8
4,000,000	2,670	5,900 1-acre	110	2,620± 90	1,030 $\frac{1}{5}$-acre	412

Since no field plots were taken on the photo surveys gross photo volumes have been made comparable to field net volume by use of the cull deductions from the field surveys.

EXTENT OF THE USE OF THESE TECHNIQUES

At present the interpretative techniques used in forest inventories vary according to the experience and training of the interpreters and to the extent that their organizations are willing to rely on aerial photos. Most inventory procedures were developed originally by foresters having little photo training Classifications, measurements, and other details were defined in terms with meaning to ground survey crews. The photo interpreter who attempts to adapt such survey procedures for aerial estimates soon finds many requirements believed by most foresters to be indispensable, are completely impractical on aerial photos. At present most techniques in use are compromises.

Classification of the forest on aerial photos with subsequent measurement of field plots is a general technique used by nearly all. The degree to which this classification is completed by stereo interpretation varies according to the classes recognized, the character of the forest, and the scale and quality of the aerial photos.

Most inventories prepare type maps, particularly if the maps are to be used for other than strictly inventory purposes. This procedure is followed by our own national forests, the surveys now being made in Canada, the U. S. Forest Survey in the West, and by surveys in many other parts of the world. Most consulting foresters confine their use of photos to the preparation of better forest maps.

But not all forest inventories insist on maps. Extensive areas covered by the U. S. Forest Survey east of the Mississippi River have been completed by photo classification and subsequent field measurement of sample plots with little or no actual mapping.

In general, few foresters have training or experience in quantitative interpretation; many use some form of qualitative interpretation, while others have progressed no further in their use of photos than to consider them as a glorified form of field map sheet. Equipment in use varies all the way from a lens stereoscope to the Multiplex, though emphasis is still on the less complicated and least expensive types.

Conclusions

1. The history of aerial photos in forest inventory can be traced through the publications of the past 30 years. It shows that many of the present interpretative techniques were visualized by early pioneers.

2. The forest can be classified and measured on photos by a mapping procedure or a sampling procedure. Both make use of the same qualitative interpretations.

3. Most forest inventories require some field work but the number of field plots needed can be greatly reduced by quantitative interpretation using aerial volume tables. On reconnaissance-type forest inventories, field work may not be needed if adequate aerial volume tables are available.

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