when the soils are slow to absorb the effluent from septic tanks. Industrial sites are carefully studied with reference to ground water supply especially important in the chemical, power and distilling industries. Flood protection measures and transportation facilities are common problems well solved by surveys based upon aerial photographs.

In Ethiopia, Burma, India and elsewhere, intensive surveys requiring skill and experience are applying aerial photography to the field of urban and land planning.

Conclusion

Aerial photography goes a long way in solving all these problems. It's a sad fact that much field work (excluding ground control) is done in a haphazard and incomplete manner, and competent fact-finders are rare and expensive. Aerial photography in all of its five facets, when in the hands of qualified analysts and interpreters, is performing a necessary and valuable service.

TIMBER ESTIMATES FROM LARGE SCALE PHOTOGRAPHS*

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Abstract

A study of the possibility of greatly reducing or eliminating field work for forest surveys of high accuracy was undertaken by the author.

A block of 72 square miles in Northwestern Ontario was selected as an experimental area. This area was photographed at a scale of 1:7,200 with a standard camera and, in addition, strips crossing the area at mile intervals were photographed at a scale of 1:1,200, with the Photographic Survey Corporation's Panning Camera. Tests showed that this camera eliminated 66% of the blur due to image motion.

Twenty-two uniform forest types ranging in size from 3 to 20 acres were sampled on the ground by 0.1 acre plots to an accuracy of ±5% at 0.95 probability for average height, average crown cover and average basal area. Measurements of crown diameter, crown length, and full descriptions of each plot were also recorded.

After testing a number of methods of height measurement on the photographs, average heights for each area were determined by means of a parallax bar mounted on a parallel motion protractor on both scales of photography. The average error for the 1:7,200 scale was +0.6′ ±2.1′, and for the 1:1,200 scale +2.1′ ±0.5′, both at 0.95 probability.

After a series of experiments, a new method of crown density measurement was devised which permitted the determination of crown density on the 1:7,200 scale with an average error per type of −1.3% ±9.9%, and on the 1:1,200 scale with an average error per type of −0.3% ±5.5%, both at 0.95 probability.

Crown diameters were measured on the 1:1,200 scale with an average error of −0.09 ±0.33′ at 0.95 probability, but could not be satisfactorily measured on the 1:7,200 scale.

Stand volume tables were prepared from the field data using average stand height, average crown cover and average crown diameter. Applying the measurements of these quantities on the photographs to the stand volume tables, volumes of merchantable pulpwood were obtained and compared with the volumes measured on the ground. The average error for the 1:7,200 scale was +7.7% (+0.31 ±0.88 cunits per acre per type at 0.95 probability) and for the 1:1,200 scale, +4.3% (+1.14 ±0.48 cunits per acre per type at 0.95 probability). These results are very satisfactory and indicate the feasibility of eliminating all field work except for collecting the data for stand volume tables. Further tests are planned under other forest conditions.

It is proposed to use the two scales of photography in combination, with the large scale serving to provide samples which can be readily and accurately measured.

* Paper delivered at the Semi-Annual Meeting of the Society in Rochester, N. Y., on September 25, 1953.

Introduction

THE Abitibi Power and Paper Company has made extensive use of photogrammetric methods in its reconnais sance, inventory, and operating surveys (Losee (2, 3, 4). However, until the present study was initiated, the largest scale of vertical photography used was 1:15,840 and much field work was required, particularly for the more exact results required in operating surveys. It was therefore decided to make a study of the possibility of using larger scales to eliminate or at least reduce this field work, with a consequent reduction in costs. As a first step, the project reported here was set up to do this for softwood species only.

Photography for the project was obtained in April, 1952, and the field work was begun in mid-July the same year. At the present time a method has been worked out and tested with good results on a small area. Some further statistical analysis remains to be done and the method must be applied and checked under various forest conditions before being sure that all its weaknesses have been eliminated. This paper is therefore in the nature of an interim report and should be judged accordingly.

Experimental Area

An area of 72 square miles was selected about 120 miles north-west of Port Arthur, on the western border of the Thunder Bay District of Ontario. Figure 1 shows its location. This area was chosen because it was owned outright by the company and because it showed the best distribution of age classes and species of the various areas in company ownership. The topography of the area is marked chiefly by low, rolling ridges with a large number of lakes. The underlying rock is Precambrian but there are extensive deposits of fluvio-glacial sands and silts. Due to these deposits, drainage has been blocked in many places with the resulting formation of large areas of spruce muskeg forest.

According to Halliday,[1] the area lies in forest section B1 of his Boreal Forest Region. The ridges support a mixed forest of black and white spruce, balsam fir, paper birch and aspen. Poorly drained locations are occupied by pure black spruce with an admixture of balsam fir on their drier boundaries, and sand plains by pure jack pine. Many low lying sandy areas were taken over by jack pine following fires, and these are in process of yielding to black spruce with the gradual restoration of the humus layer. The varying stand conditions were of considerable assistance in providing a variation in measurement conditions and in giving a range in data which could not have been obtained otherwise.

Three age classes are present. The oldest is represented by only a few scattered, open stands, and it is about 110 years old. The greater part of the area is divided almost equally between 80 year old stands and 50 year old stands, both originating after fire. There are also a few all-aged black spruce stands. This range of age classes was important because it provided a range of heights on which to test the photographic measurements.

Camera

In going to larger scales in aerial photography, it is found that ordinary cameras limit use to scales smaller than 1:2,400 because of the movement of the image on the film during the exposure. Considering the probable resolution, it was not believed that this scale was large enough to give the accuracy required. In fact, the figures indicated that a scale of something close to 1:1,200 was needed to ensure a safety margin beyond the minimum requirements. It was therefore necessary to use some variety of image motion compensating camera. The Sonne camera was first considered, but the difficulties encountered in its use in forestry by Rogers[7] and Mignery[5] were not encouraging. While exploring the possibilities, the Photographic Survey Corporation of Toronto suggested the use of its Panning Camera, and after consideration of its advantages, its suggestion was accepted.

The idea behind the camera is simplicity itself. It makes use of the technique every photographer uses who wishes to take a picture of a rapidly moving object. By moving the camera with the object as it moves across his field of view and making the exposure as the camera moves, a sharp photograph can be obtained. The same thing is done with the aerial camera. During each exposure the camera is rotated on a horizontal axis, at a rate which keeps it pointed at the same place on the ground during the exposure interval. While the

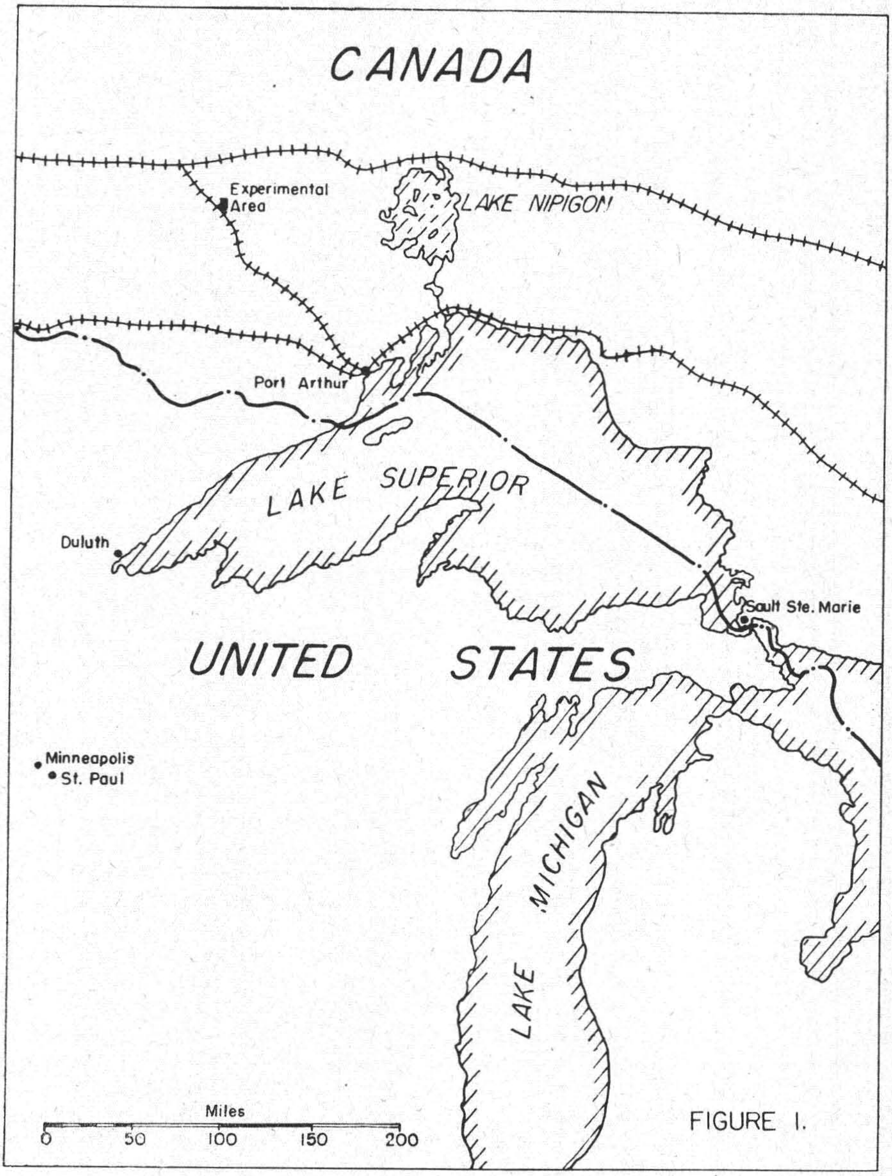

FIG. 1. General location map. Experimental area is in upper left hand corner.

shutter is closed the camera is brought forward again for the next exposure.

Measurements on resolution targets laid out on the ground in the area photographed showed that the Photographic Survey Corporation's Panning Camera was successful in eliminating 66% of the blur due to image motion. As a result, the photography was excellent. Since this was the first commercial job undertaken with the camera, even better results can be expected in the future.

The Panning Camera is equipped with a 24 inch lens, which, with its 9 inch×9 inch format, is the chief advantage it has over the Sonne camera. The long focal length reduces the difference in scale between the tree tops and the ground to a point where it can be neglected. With a ground scale of 1:1,200, the top of a 50 foot tree is photographed by the 24 inch lens at 1:1,175 and by a 4 inch lens, as used by the Sonne, at 1:1,050. A further advantage is the reduction of the displacement of the tree tops in the corners of the photographs. This allows the interpreters to fuse the tree images without difficulty, and contributes substantially to the identification of species as well as to the ease of making measurements of height and density. A third advantage of the 24 inch lens is that with the one aircraft, large scale coverage can be obtained of part of the area at the same time that a second camera equipped with a 6 inch lens obtains complete coverage at a smaller scale.

Photography

In line with the limitation of the work to softwood volumes, the first decision in regard to photography was that it should be taken with the hardwoods leafless and with snow on the ground. Under these conditions the softwoods are much more easily seen and measured. In addition, the snow background increases their contrast, and therefore their resolution.

Vertical photography was chosen in preference to tricamera photography because of the difficulty in estimating density on the tricamera obliques. A second disadvantage to tricamera photography in company operations is that men untrained in photogrammetry must also use it and they have difficulty in appreciating the perspective involved.

Panchromatic photography was specified because the large scales used eliminated the advantages of the tone distinctions of infrared. At the 1:1,200 scale especially, our species can be identified better by crown from than by tone. In addition, extremely high contrast conditions prevail in winter photography and these would be exaggerated even by modified infrared photography to the point where the shadow detail would be eliminated. Panchromatic film itself requires full exposure and shortened development if the best results are to be obtained.

To explore the range of scales below the inventory scale of 1:15,840, and yet keep costs to a reasonable figure, it was decided that complete coverage of the area would be obtained at 1:7,200, with strips of 1:1,200 photography at mile intervals. A 6 inch lens was used for the 1:7,200 scale and a 24 inch lens, as previously mentioned, for the 1:1,200 scale. This arrangement will permit determining the accuracy and cost of estimates at the two scales separately and in combination.

Height Measurements

HEIGHTS OF SINGLE TREES.

In order to determine the correction factors required for snow depth, lack of resolution, the personal equation, and any other factors which might be operative 189 trees were accurately measured in the field. On returning to the office, a series of experiments was made to determine the most accurate method of measuring tree heights under the particular photographic and field conditions obtaining. Space does not permit giving a detailed description of these experiments, but this is planned for a later paper. From the experiments it was concluded that the parallax bar mounted on a parallel motion protractor gave the most accurate results with a reasonable expenditure of time.

Correction factors, as shown in Table 1, were obtained from these experiments, by averaging, for each species or group of species, and for each interpreter, the differences found between the heights measured in the field and on the photographs. As the trees were divided into two groups to assist in the statistical analysis and only one group has been completely measured to date, and because some trees proved to be impossible to measure on the 1:7,200 photographs, these correction factors are based for the present on measurements of only 64 trees. This number includes only a few of the white spruce and balsam fir, and so these trees were grouped with black spruce. This was possible since the black spruce were almost entirely upland trees, and therefore all three species had similar crown forms. Had the black spruce been typical bog spruce, this grouping could not have been used as the corrections for lack of resolution would have been different, at least at the 1:7,200 scale.

The difference in magnitude between the correction factors for the two scales must be due almost entirely to the difference in the correction required for lack of resolution. The corrections for the 1:1,200 scale do not differ significantly from zero and may be neglected. Therefore the personal correction for the interpreters must be negative, as snow depth requires a positive correction of approximately 3 feet even if the positive correction for resolution can be ignored.

TABLE 1

CORRECTION FACTORS FOR TREE HEIGHTS

	1:7,200 Scale	
	Black Spruce White Spruce Balsam Fir (37 trees)	Jack Pine (27 trees)
Interpreter A	+ 9.9′	+ 9.8′
Interpreter B	+15.9′	+15.3′
Interpreter C	+10.5′	+13.1′
	1:1,200 Scale	
	Black Spruce White Spruce Balsam Fir (37 trees)	Jack Pine (27 trees)
Interpreter A	+0.7′	0.0
Interpreter B	−0.8′	−1.5′
Interpreter C	+1.8′	−0.7′

However, snow depth measurements taken at the time of photography are available, and will be used at a later date to refine these correction factors by assigning a given snow depth to a particular situation defined by topography and forest cover. Further analysis of the other factors involved is also planned.

AVERAGE STAND HEIGHT

Seven spruce and five jack pine stands were sampled on the ground for height to an accuracy of ±5% of the average height of 0.95 probability. On the photographs at both scales, dominants or co-dominants were selected by means of a grid at regularly spaced intervals in each of these stands and measured by the parallax bar. Sufficient heights were taken in every case to reduce the sampling error to less than ±5% at 0.95 probability. (This, while not a valid sampling error, was useful as a comparative measure.) Usually this required 15 to 20 measurements. In the case of the 1:7,200 scale the individual heights were adjusted by means of the correction factors in Table 1. As a further adjustment, the individual measurements of types having less than 70% crown cover on the 1:7,200 scale and all types on the 1:1,200 scale were weighted by volume. This helped to compensate for the interpreters' tendency to select shorter trees in these cases. The results are shown in Table 2.

TABLE 2

COMPARISON OF FIELD AND PHOTOGRAPHIC MEASUREMENTS OF AVERAGE STAND HEIGHT

Type	Field Measurement	Photo Measurement		Error	
		Scale: 1:7,200	Scale: 1:1,200	Scale 1:7,200	Scale: 1:1,200
	ft.	*ft.*	*ft.*†	*ft.*	*ft.*
19-6	50.5	53.2	54.2	+2.7	+3.7
20-2	58.4	54.7	59.1	−3.7	+0.7
20-5	49.8	45.6	48.9	−4.2	−0.9
20-6	46.7	47.7	50.9	+1.0	+4.2
21-1	54.1	60.4*	51.7	+6.3	−2.4
24-1	50.9	50.1*	52.1	−0.8	+1.2
24-2	48.5	45.9*	52.5	−2.6	−4.0
21-3	53.1	57.1	56.0	+4.0	+2.9
22-1	60.4	64.1	60.0	+3.7	−0.4
22-6	50.0	49.9	53.4	−0.1	+3.4
23-1	45.7	44.6	49.0	−1.1	+3.3
23-2	43.1	44.7*	48.3	+1.6	+5.2

Average error on 1:7,200 scale = +0.6′ ±2.1′ (at 0.95 probability).

Average error on 1:1,200 scale = +2.1′ ±0.5′ (at 0.95 probability).

* Individual measurements weighted by volume since these stands have less than 70% crown cover.

† All measurements on this scale weighted by volume.

The difference in average error for the two scales is not significant.

The results on either scale of photograph are satisfactory, but the lower standard error and a somewhat shorter time required for measurement indicate the superiority of the larger scale. However, this superiority for height measurements alone is not sufficiently great to justify the use of the more costly photography.

Density Measurements
Development of the Method

As test material, the same 12 type areas mentioned in the test of average height determination were used. These types were sampled on the ground for basal area and crown cover by means of tenth-acre square plots distributed at random through the type. Sufficient plots were measured to bring the sampling error down to ±5% of the average for basal area and crown cover, at a probability of 0.95. The crown diameters of 15 to 25 merchantable trees selected at random were also measured on each plot.

The crown cover was measured by means of the Dominion Forestry Branch "Moosehorn," which has been reduced in size and coverage since described by Robinson.[6] In using the latter instrument, every effort was made to obtain reproducibility of results. One man made all the measurements, level bubbles were installed at right angles to one another inside the instrument, and definite rules were laid down as to which crowns should be included in the measurement. In spite of this, considerable difficulty was met until enough readings were taken to completely cover the plot area at the average height at which the crown diameters were greatest. A test in which 5 determinations of crown cover were made for the same plot by the same man, with each determination consisting of 100 readings, gave a standard error for the average crown cover of ±1.7% with a probability of 0.95.

On returning to the office an investigation of methods of determining crown closure from the photographs was begun. In these tests the first aim was to devise a method which would give a high order of reproducibility of measurements. An equally important aim was to obtain a relationship between these photographic measurements and either crown closure or basal area. Related to this last aim was the additional one of finding a photographic method which compressed the scale of density measurement as little as possible.

Various density measurement overlays and techniques were tried. The method used was to attach the overlay or pair of overlays firmly to the photographs and have each interpreter in turn make an independent series of 40 readings. When all three, or in some cases four, interpreters had done this, the results were compared. Each type of overlay and technique was tested by having each interpreter make a minimum of 5 such series of readings. It was found necessary to complete all the readings for one position of the density measurement overlay during one work period. If the overlay were left over the noon hour, or particularly over night, changes in print dimensions caused by changes in humidity were sufficient to alter the readings completely.

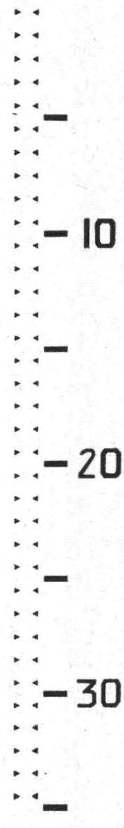

FIG. 2. Density measurement overlay.

The overlay finally chosen on the basis of the tests was an original design which is illustrated in Figure 2. This has the great

TABLE 3
COMPARISON OF THE ACCEPTED TECHNIQUE WITH THE BEST OF THE DISCARDED TECHNIQUES

	Accepted Technique	Technique A*	Technique B†
Number of series of 40 readings by each interpreter	5	6	5
Number of interpreters	3	3	3
Standard Error of interpreters' estimates at 0.95 probability	±5.8%	±8.0%	±8.8%
Samples agreed on	78%	64%	47%
Range in reading for 46% range in field measurement	30%	15%	—

* Technique A required the interpreter to estimate whether the sample was less or more than 50% crown using stereoscopically fused overlays.

† Technique B was identical with Technique A except that only one overlay was used in estimating on the stereo model.

advantage of not obscuring the crown cover being sampled. The apices of the pairs of triangles define very closely an imaginary line connecting them. The estimate of density is made along this imaginary line. Because only one dimension is used, it is possible for a careful and experienced interpreter to make such an estimate consistently. Various separations of the apices of the triangle were used, but 0.01 inches proved most satisfactory for the 1:7,200 scale, and for comparative purposes this determined a separation of 0.06 inches for the 1:1,200 scale.

The technique finally selected used stereoscopically fused overlays, with the interpreters deciding for each density sample whether or not any part of a crown crossed the sampling line. If any part of a crown did so, the sample was recorded as "crown"; if not, as "gap." The percentage of samples recorded as crown gave the per cent crown cover. The combination of the overlay of Figure 2 and this technique gave the least variation between interpreters, the largest percentage of samples agreed on by all three interpreters, and the greatest sensitivity to changes in stand density as measured on the ground. Table 3 illustrates this.

DENSITY MEASUREMENTS
CORRELATION BETWEEN FIELD AND PHOTOGRAPHIC MEASUREMENT

PHOTOGRAPHY AT A SCALE OF 1:7,200

Once the technique of measuring the density of stands on photographs had been perfected, it was applied to the 12 previously sampled spruce and jack pine types. In every case sufficient estimates of density were made to reduce the sampling error to 5% or less. Lines of 40 samples each rather than individual samples were taken as the unit, and 12 such lines were usually sufficient.

In analysing the correlation between the photographically determined density on the 1:7,200 scale and field measurements for the spruce stands, it was found necessary to introduce distance from the principal point as a factor. The reason for this was that the strong displacement of the 6 inch lens used for this photography reduced the apparent size of the crown openings toward the edges of the photographs. However, when this was allowed for, the correlation was very good.

With jack pine it was found necessary to use crown diameter as a variable in the analysis of the same correlation. This was not due to the direct effect of crown diameter but because of its correlation with the number of trees under 5 inches in diameter. Trees of this size are not merchantable and are not included in the calculation of crown cover from crown diameter measurements. They are, however, visible in the 1:7,200 photographs and enter into the photographic determination of crown cover. When such trees are present, the average crown diameter of the stand is reduced in proportion to their number, and this allows a useful correlation to be made.

In the jack pine correlation, distance from the principal point was not a significant factor since most of these types occurred close to the principal point of the

TABLE 4
COMPARISON OF FIELD AND PHOTOGRAPHIC MEASUREMENTS OF CROWN COVER

Type	Crown Cover Per Cent			Error	
	From Field Tally	From 1:7,200 Photo Measurements	From 1:1,200 Photo Measurements	Scale: 1:7,200	Scale: 1:1,200
19-6	49.0	43.8	56.5	− 5.2	+ 7.5
20-2	61.6	53.2	62.6	− 8.4	+ 1.0
20-5	50.7	78.0	50.8	+27.3	+ 0.1
20-6	54.4	43.5	64.6	−10.9	+10.2
21-1	25.8	28.1	18.6	+ 2.3	− 7.2
24-1	27.2	28.4	37.8	+ 1.2	+10.6
24-2	21.0	20.1	25.0	− 0.9	+ 4.0
21-3	48.5	54.4	45.5	+ 5.9	− 3.0
22-1	56.2	53.6	57.0	− 2.6	+ 0.8
22-6	38.8	56.3	37.8	+17.5	− 1.0
23-1	50.4	45.4	44.8	− 5.0	− 5.6
23-2	54.3	18.0	33.0	−36.3	−21.3

Average error on 1:7,200 = −1.3% ± 9.9% (at 0.95 probability).
Average error on 1:1,200 scale = −0.3% ± 5.5% (at 0.95 probability).
The difference between the average error at the two scales is not significant.

photographs on which they appeared.

The accuracy of the estimates made on photographs at the scale of 1:7,200 for each of the 12 coniferous experimental types using the correlations established is shown in Table 4.

PHOTOGRAPHY AT A SCALE OF 1:1,200

In determining stand density on photographs at this scale, the density overlay was enlarged six times so that the samples taken would be equivalent statistically to those taken on the 1:7,200 photographs.

Stands predominantly jack pine and those predominantly spruce were again treated separately at this scale. Because of the 24 inch focal length of the lens used for these photographs, distance from the principal point as a factor was reduced below the level of significance. Crown diameter was effective, however, for both types of stand.

The accuracy of the estimates of density for each of the 12 experimental coniferous types made on photographs of this scale is shown in Table 4.

Table 4 shows that with only 12 types, the standard error is too great using the 1:7,200 scale and that it just exceeds the arbitrarily chosen standard of ±5% using the 1:1,200 scale. However, no operating survey under the forest conditions met in Abitibi's timberlands would ever have so few types in a camp area. The minimum is probably in the neighbourhood of 30, with the average about 75. The standard error of stand densities determined by this method would therefore be satisfactorily reduced in practice.

In addition to the lower standard error, the 1:1,200 scale allows density measurements to be made in less than one-third the time required on the 1:7,200 scale. This by itself would justify the cost of the partial coverage at the larger scale.

CROWN DIAMETER MEASUREMENT

In the first attempts to measure the crown diameter of the sampled stands on photographs, very disappointing results were obtained on both the 1:1,200 and 1:7,200 scales. The personal bias of the individual interpreters, using a simple scale with a magnifier on single photographs, was so great that their measurements could only be used with extreme caution after correcting for it. It therefore became necessary to measure the crown widths on a stereo model. Following the suggestion of the speaker's assistant, Mr. Atkinson, a parallax bar was used with the fixed mark removed, setting the bar of the cross of the movable mark, which was parallel to the *Y*-axis of the photographs, first on one side of the crown and then on the other. The crown width could then be

TABLE 5

COMPARISON OF FIELD AND PHOTOGRAPHIC MEASUREMENTS OF AVERAGE CROWN DIAMETERS

Type	Crown Diameters (ft.)			Error (ft.)
	From Field Measurements	From Photos at 1:7,200 Scale	From photos at 1:1,200 Scale	Scale 1:1,200
19-6	5.7		5.8	+0.1
20-2	7.1		7.4	+0.3
20-5	6.6		6.3	−0.3
20-6	7.3		7.5	+0.2
21-1	5.3	Not	5.4	+0.1
24-1	7.7	measured	8.1	+0.4
24-2	6.4		7.4	+1.0
21-3	6.8		6.0	−0.8
22-1	7.9		7.5	−0.4
22-6	6.1		5.5	−0.6
23-1	7.5		7.1	−0.4
23-2	9.8		9.1	−0.7

Average error = −0.09′ ±0.33′ with a probability of 0.95.
The average error does not differ significantly from zero.

read on the parallax bar's scale. Time was saved by using the last reading on one crown as the first setting for the next crown After working out the sampling error for a number of types, it was found that 30 measurements were sufficient to reduce the error to less than 5% under the most variable conditions met in these tests, and since these measurements were quickly made, this number was adopted as a standard. The time saved in omitting the calculation of sampling error was more than sufficient to compensate for the unnecessary measurements made in unusually uniform stands.

The relationship between the measurement on the 1:1,200 photographs and the field measurement was not straight as expected, but curvilinear. The correlation was very strong but the range of values of the photographic measurements, 5.4 to 9.1 feet, was somewhat reduced compared to the field measurements which gave a range of 5.3 to 9.8 feet. It is probable that in the larger-crowned open stands more small trees were measured, and in smaller-crowned dense stands more small trees were overlooked. The crowns for measurement were selected at regular intervals by means of a transparent overlay, but even this was insufficient to overcome these tendencies.

A very weak correlation was obtained between the measurements on the 1:7,200 photographs and the field measurements. It was evident that the instrumental errors in measurement, together with the personal factors, were too great for accurate measurement on this scale of photography. Actually, the crowns being measured were small, as the figures in the preceding paragraph show, so that even errors of a foot were relatively large.

Table 5 shows the actual errors in average crown diameter measurement for the 12 coniferous experimental types.

STAND VOLUME TABLES

The plots used for sampling the experimental types also supplied data for stand volume tables. In analysing these data, they were divided into three groups:

1. Predominantly spruce types,
2. Mixed softwood and hardwood types,
3. Predominantly jack pine types.

TABLE 6

ACCURACY OF STAND VOLUME TABLES

Type	Standard Error of Estimate	No. of Tenth-Acre Plots
Spruce types	±3.4 cunits*	50
Jack Pine types	±1.5 cunits*	45
Mixed types	±1.8 cunits*	33

* One cunit = 100 cu. ft. of wood.

TABLE 7

COMPARISON OF VOLUMES PER ACRE MEASURED ON THE GROUND AND ON PHOTOGRAPHS

Type	Area	Volume by Field Measurement	Volume by Photo Measurement	Error	Area×Error
	acres	*Cunits/ac.*	*Cunits/ac.*	*Cunits/ac.*	*Cunits*
1:1,200 SCALE					
Black Spruce Types					
19-6	2.70	25.4	26.2	+ .8	+ 2.160
20-2	3.99	29.7	29.0	− .7	− 2.793
20-5	1.98	19.0	19.9	+ .9	+ 1.782
20-6	7.50	16.1	21.4	+5.3	+39.750
21-1	6.90	18.6	14.8	−3.8	−26.220
24-1	5.67	10.6	15.6	+5.0	+28.350
24-2	10.30	12.0	11.5	− .5	− 5.150
Jack Pine Types					
21-3	12.12	16.1	20.0	+3.9	+47.268
22-1	8.89	27.5	25.7	−1.8	−16.002
22-6	4.80	16.7	17.8	+1.1	+ 5.280
23-1	14.05	11.6	13.1	+1.5	+21.075
23-2	8.90	6.9	8.9	+2.0	+17.800
				Total error:	+108.55 cu., or 7.7% of field estimate.

Average error per type: +1.14±0.48 cunits per acre at 0.95 probability.

Type	Area	Volume by Field Measurement	Volume by Photo Measurement	Error	Area×Error
1:7,200 SCALE					
Black Spruce Types					
19-6	2.70	25.4	20.8	−4.6	−12.42
20-2	3.99	29.7	24.1	−5.6	−22.34
20-5	1.98	19.0	20.6	+1.6	+ 3.17
20-6	7.50	16.1	16.5	+ .4	+ 3.00
21-1	6.90	18.6	24.7	+6.1	+42.09
24-1	5.67	10.6	14.6	+4.0	+22.68
24-2	10.30	12.0	8.8	−3.2	−32.96
Jack Pine Types					
21-3	12.12	16.1	20.4	+4.3	+52.12
22-1	8.89	27.5	36.5	+9.0	+80.01
22-6	4.80	16.7	14.5	−2.2	−10.56
23-1	14.05	11.6	9.6	−2.0	−28.10
23-2	8.90	6.9	2.8	−4.1	−36.49
				Total error:	+60.20 cu., or 4.3% of field estimate.

Average error per type: +0.31±0.88 cunits per acre at 0.95 probability.

Data from each group were analysed using Ezekiel's graphical technique for the analysis of multiple curvilinear correlations. While it is not as elegant a technique as a mathematical analysis, it is a good deal less time-consuming and the results are at least as accurate because they are not distorted by the use of equations whose form cannot exactly fit the data.

Volume per acre of trees 5 inches and over at breast height was the dependent variable; average stand height, average crown cover, and average crown diameter were the independent variables. The average height of the trees measured was weighted by volume to reduce the effect of the variable judgments met in classifying trees as dominants and co-dominants Both "moosehorn" measurements and crown cover calculated from crown diameter were used in different analyses. The calculated crown cover showed itself consistently more closely related to volume than the "moosehorn" crown cover. Crown diameter did not appear to be well correlated with jack pine volume but showed a good correlation in other types.

Standard errors of estimate for estimated volume plotted on actual volume are presented in Table 6.

Test of Method

In making a test of the method, the average heights, densities, and crown diameters for each type, determined in the tests already described, were used to estimate volumes per acre from the stand volume tables. Table 7 presents the results obtained.

The greater bias in results for the 1:1,200 scale is due chiefly to the bias in the height measurements at this scale, and it should be possible to adjust for this after further tests have been made. With the number of degrees of freedom available, neither of the errors shows a significant difference from zero, nor do they differ significantly from each other. The standard errors, however, indicate the greater reliability of the measurements on the 1:1,200 photographs.

The results are very satisfactory even as they stand now, and within the limits of this test, they show that the elimination of field work is a practical possibility. Tests under other forest conditions are desirable, of course, and it is hoped to make them in the near future using the volume of wood actually cut as the standard for comparison.

Application

A study of the costs of the methods developed in this work shows that the 1:1,200 scale cannot be used exclusively because of the cost of photography, nor can the 1:7,200 scale be used because of the cost of interpretation. The solution is therefore to have the two scales flown simultaneously, using a 36 inch and a 6 inch camera in the one aircraft. The large-scale photography would then provide a sample strip down the center of each flight of 1:7,200 photography. Estimates made from measurements on the large-scale photographs would be applied to type areas designated on the smaller scale, following regular sampling procedures. With this method, it is believed that detailed pulpwood surveys can be made economically under the conditions described above, without setting foot on the ground after the data for stand volume tables have been obtained.

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