

Forest Research Branch

# TREE MEASUREMENTS ON LARGE-SCALE, VERTICAL, 70 mm . AIR PHOTOGRAPHS 

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# Tree Measurements on Large-Scale, Vertical, 70 mm . Air Photographs ${ }^{1}$ 

by<br>F. W. Kippen and L. Sayn-Wittgenstein ${ }^{2}$

## INTRODUCTION

The purpose of the study was to determine how accurately trees could be measured and identified on photographs taken at the very large seale of $1: 1,200$. Such photographs may be employed in forestry to gather detalled information that cannot readily be obtained with sufficient accuracy from photographs of smaller seales. Examples are: tree species, tree form and quality, incidence of diseases and insect infestations, crown canopy density, number of trees per unit area, and the height, crown width or stem diameter of individual trees. In general the information sought from large-scale photographs is roughly the same as that collected on the temporary sample plots of a ground survey.

In recent ycars investigations of large-scale photography for forestry purposes have been initiated in Canada, in the United States and in Russia. It is perhaps signifcant that these investigations have remained confined to countries with large forested areas, while in countries with smaller forests the photographs used are almost exclusively taken at seales that lie between $1: 10,000$ and $1: 15,000$, and the trend is perhaps to even smaller scales. (von Laer, 1962). In the countries with easily accessible forests, such as those of western Europe, detailed information about the forest can easily be obtained on the ground, while in countries such as Canada one hopes to eliminate or reduce the amount of field work and to replace or supplement it by less expensive photo sampling techniques.

## Review of Past Work

It is difficult to determine when and where the first trials of large-seale photographs for forestry purposes were made. Probably the first persons to use air photographs realized that they could have obtained more information from their photographs, had they used a larger scale.

Experimental work in Canada with large-scale photographs was begun many years ago near the Petawawa Forest Experiment Station, which still serves as a test area for air photography experiments of the Department of Forestry. In 1928 trials of air photographs taken at the relatively large scale of 1:6,000 (Figure 1), were made (Losee, 1942), and in 1932 winter photographs at a sole of 1:1,800 were tested.

The decade following World War II saw several trials of large-scale photographs. The results of these experiments generally defined the main problems: difficulties in the accurate determination of scale were encountered and it also became apparent that if accurate measurements were to be made, sharper and better air photographs were necessary. Image motion was recognized as a most important factor restricting image quality, and much work was devoted to overcoming this problem, for example rather successful experiments using panning cameras were carried out in Canada by Losee (1953).

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Froume 1. Fall photograph at scate of $1.6,000$ taken in 1928 at the Petawawa Forest Experiment Station, Ontario (A.C.A.F, photograph).

Image motion due to the fortward movement of the aircraft was largely overcome by the image-motion-compensating Sonne cameras which yielded photographe of outstanding sharpness (Figure 2). But, while there are reports of the accurate measurement of trees on Sonne photographs (Pallin, 1960), such photographs have generally not been successfully used for reliable measurements. The


Frover 2. Sections of Sonne photographs taken in 1950 (scale 1:510). From left to right cows in a pasture, farm fence, felled trees.

Forest Research Branch carried out extensive trials of Sonne photography between 1950 and 1954 and it was found that most tree species could be recognized on such photos, but that the photogrammetric problems caused by the continuously open aperture were too great to be overcome in practice, although sometimes very precise tree diameter measurements were obtained.

Somewhat related experiments were carried out in Russia with oblique photography taken with a continuous motion slit camera. (Gorodeev, 1961). Winter photographs at very large scales were taken and it is reported that satisfactory results were obtaned when measuring the height and the diameter of trees. From the reference cited it is however not clear to what extent this photography has proved useful in practice as most of the statements about the precision of measurements appear to be theoretical estimates and not the result of experience in measuring trees.

During these years the films available for air photography were being steadily improved, and cameras with better lenses and capable of higher shutter speeds were being developed. A major step forward was made as cameras with very high shutter speeds and a small film format ( 70 mm .) became available for forest surveys. A most important development was the successful use of a Hulcher 70 mm . camera in insect damage surveys in the United States (Aldrich, Bailey, and Heller, 1959) and the subsequent expansion of this work to include the detailed investigation of species identification on such photographs. (Doverspike and Heller, 1962; Heller, Doverspike and Aldrich, 1963).

In the meantime, Avery undertook experiments with photographs taken from helicopters using a stereo-mount of two hand-cameras and demonstrated that trees could be accurately measured and identified with such photographs; but what is perhaps more important, Avery described some of the problems encountered and made recommendations for future tests. (Avery, 1958, 1959).

The British Columbia Forest Service continued the investigation of helicopter photography and followed some of Avery's recommendations by using a longer beam between the two cameras. An encouraging result of this study was that at a altitude as low as 250 feet the estimate of flying height had a standard error of only 1.76 per cent; photographic scale was therefore accurately determined. (Anon., 1960; Lyons, 1961).

Early in the spring of 1961, when most of the ground was still covered by snow, the Forest Research Branch arranged for large-scale photographs to be taken to investigate the forest mensurational possibilities of winter photography, the advantages of which have long been advocated by Seely. These photographs were taken with a Vinten 70 mm . camera, having a 4 -inch lens, employing a shutter speed of $1 / 1,000$ second and a scale of $1: 2,400$. As Seely (1962) has pointed out in his preliminary appraisal the photographs showed excellent image quality and many trees could be easily examined because deciduous foliage was absent, and shadowed areas were illuminated by reflection from the snow.

However, attempts to measure tree heights, crown widths, and stem diameters on these photographs were generally disappointing; on a few photographs the accuracy of measurements was acceptable, but on others large errors were made. It was established that the chief cause of inaccuracies was tilting of the camera axis; air turbulence may have been particularly great because of the alternation of upward and downward air currents which developed over bare ground and snow-covered areas.

This investigation confirmed what had been suspected earlier: the most important remaining problem with large-scale photography was the accurate assessment of photographic scale.

## The 1962 Trials

In the spring of 1062, new photographs were taken at the letawawa Forest Experiment Station to continue the tests of the accuracy with which trees can be measured and identified.

The investigation did not deal directly with the determination of rolume of trees and stands, but rather with the aceuracy of collecting those data that may form the basis of volume estimates. Sampling units, equivalent to $1 / 5$-acre plots on the ground, were established on the photographs and for the trees on these plots the accuracy of tree counts, species identification, the measurement of tree heights, crown diameter and stem diameter was determined.

Furthermore, the new trials were to investigate the possibility that lenses with longer focal lengths would allow a more accurate determination of photographio seale.

## METHODS

A lens of 12 -inch focal length was used instead of the previously tested 4 -inch lens. In other respects the 1962 trials were similar to the previous experiments: again a Vinten camera was used and the photographs were taken when the ground Was snow-covered; panchromatic Super XX film was employed and photographs were exposed at a shutter speed of $1 / 2,000$ second. The scale of photography was $1: 1,200$ or 100 feet per inch. (Figure 3).

The tests were concentrated on a strip of 150 photographs; four-times enlargements of these photographs were prepared because they were found more convenient to work with.

First, radial line plotting was used to establish the scale of the individual photographs in this strip. Two roads, approximately one mile apart, were selected as control points for the strip and the distance between them was obtained from a $1: 25,000$ military map.

Next, ten of the photographs were chosen at random, and a square, one-fifth acre plot was located at the centre of each photograph, with the photo dimensions of the plot based on the scale determined by radial line plotting.

All trees over twenty feet high, that were visible inside the plots, were measured. Total height was measured with a parallax bar and crown diameter with an engineers' scale; crown diameter was measured at right angles to the line drawn from the principal point through the crown centre. A count of the number of trees per plot was obtained and the interpreter recorded the species to which he believed each tree belonged. On three plots, diameter at breast height was measured for all trees which were visible.

After all photo measurements were completed a field party was sent out to check the measurements of each tree. Tree heights were measured with a hypsometer and stem diameters with callipers. Two men measured crown diameters; one, with a plumb-bob, standing at a distance from the tree, lined-up the other one below the cxtreme limits of the crown; the points below these limits were marked on the ground and the distance between them was measured. Crown diameter and stem diameter measurements were taken along the same direction as the corresponding measurements on the photographs, that is at right angles to the line drawn from the principal point through the centre of the tree.

All the trees encountered on the plots were placed into one of three categories: pines, hardwoods, or spruce and fir, and a separate analysis was made for each group.

The linear regression of air photo over ground measurement was calculated, and in addition a Chi-squared test was made to determine whether or not the photo measurements met given standards of accuracy.


Figtre 3. Examples of 70 mm . photographs. Top: a stereogram at 1:1:200; bottom: a four-times enlargement to a scale of 1:300.

Freese (1960) has pointed out the advantages of this test over the t-test when comparing a new method with a standard one (in our case photo measurements with ground measurements). If the t-test is used a new method is generally considered acceptable if the difference between its result and that of the standard method is "not significant". This may lead to absurd results: one method may prove acceptable because it has such low precision that all evidence of significant differences between means disappears, while another method with a very small bias may be rejected because it is so precise that bias shows up clearly.

## RESULTS

## Height

The photo measurements slightly underestimated tree height (Table 1); this is probably a consequence of some loss of resolution and is usual for photo measurements of height.

In evaluating the standard errors of estimate obtained one must remember a very important difference between this test and the usual procedure of obtaining tree heights on air photographs: in our tests every tree that could be seen within the plots was measured; on small-scale photographs one usually measures only those trees that can easily be seen, such as those in the open or near clearings. If such a subjective method of tree selection had been employed, then undoubtedly better results would have been obtained, because many of the larger errors were made when measuring small trees which were hidden by taller trees, or were obscured by dark shadows that fell over them. Inaccurate height measurements of this kind were frequent with small spruce and fir trees that tended to grow in clumps under an overstorey of hardwoods. On very sharp photographs at a scale of $1: 600$ that have since become available the measurement of trees in the understorey proved more difficult than at the smaller scale. Apparently a multitude of fine branches that did not resolve at a scale of 1:1,200 showed up clearly at the larger scale and greatly confused the picture of trees in the understorey.

TABLE $1-$ SUMMARY OF HEIGHT MEASUREMENTS

|  | Pines | Spruce and Fir | Hardwods |
| :---: | :---: | :---: | :---: |
| Regeression equation*: $Y=$ | $-0.75+0.989 \mathrm{X}$ | $0.25+0.976 \lambda^{-}$ | $0.18+0.980{ }^{-}$ |
| Mean photo measurement (ft.) | 73.91 | 38.18 | 50.26 |
| Mean field measurement (ft.). | 75.49 | 38.80 | 51.10 |
| Diference (tt.) | $-1.58$ | $-0.68$ | $-0.84$ |
| Stundard error of estrmate (tit.) | 2.70 | 3.23 | 3.67 |
| Number of measurements. | 139.00 | 178.00 | 153.00 |

* $Y$ is the photo measurements, and $X$ the feld measurement.

The heights of hardwoods were determined with the least accuracy. This may be explained by the irregular crowns of many trees, by the fine branches that were often not resolved on the photo, and by the difficulty that was occasionally encountered in examining trees with light bark against a background of snow. Perhaps this low accuracy should not be very disturbing, because total height of hardwoods is a parameter of somewhat questionable value for estimating merchantable volume; the possibility of estimating usable length should be investigated.

TABLE 2-STANDARDS OF ACCURACY REACHED IN THE MEASUREMENT OF TOTAL HEIGHT (95 per cent probability)*

| Standard of Accurdry (feet) | Pines | Spruce and Fir | Hardwoods |
| :---: | :---: | :---: | :---: |
| $\pm 5$ | reject | reject | reject |
| $\pm 6$ | accept | accept | reject |
| $\pm 7$ | aceept | accept | aceept |

* For example, the photo measurements of hardwoods must be rejected if we require that the photo measurement be within 45 beet of the groumd measurement with a probability of 95 per cent; the same is true if the required accuracy is +6 feet, but we can accept the photo measurements if we are prepared to lower our standard of acenacy to $\pm 7$ feet.

Oceasionally it was difficult to measure the height of balsam firs, because the dense tops of these trees reflected so much light that ther appeared almost white on the photo, and the interpreter had difficulty in defining the top.

The accuracy of the results obtained has been reduced by two assumptions that were necessary. Some growth in tree height had occurred between the time of photography and the date when the ground measurements were made; in the field the average height growth was estimated as one foot, and this figure was added to the photo measurements. Furthermore, snow covered most of the ground at the time of photography, and again a correction based on the estimated average snow depth (one foot) was made.

The movement of tree crowns by wind may seriously impair the accuracy of tree height measurements (Aldred, 1963); for example, if the top of a 67 foot tree moves by one foot, between exposures, parallel to the line of flight, then the error exceeds five feet.

Finally one must remember that the ground measurements which in the analysis are assumed to give the true height of the trees, probably contain errors.

## Crown width

TABLE 3 SUMMARX OF CROWN WIDTH MEASUREMENTS

|  | Pine | Spruce and Fir | Mardwoods |
| :---: | :---: | :---: | :---: |
| Regression equation*: $\mathrm{X}^{*}=$ | $1.8+0.839 x$ | $1.38+0.802 \times$ | $-1.02+0.935 \mathrm{x}$ |
| Mean photo masasurement (ft.) | 18.50 | 11.40 | 17.83 |
| Mean freld measurement (it.). | 19.00 | 12.00 | 19.63 |
| Difference (ft.). | $-1.40$ | $-0.60$ | $-2.30$ |
| Standard error of estimate (it.). | 2.03 | 1.54 | 2.32 |
| Number of measurements. | 100.00 | 178.00 | 153.00 |

*I is the photo measurement and $\lambda$ the field measurement.
As expected, the photo measurements of the crown width of spruce and fir were eloser to the ground measurements than those of the pines with their more irregular crown shapes; and the hardwoods were measured with the least accuracy.

The results of the measurement of crown width are difficult to evaluate, because for both the ground and the photo measurements much subjective judgement is involved. Accurate measurements were impossible because of interlocking or poorly defined crowns; this difficulty was greatest with small trees, especially

TABLE 4-STANDARDS OF ACCURACI REACHED TN THE MRASUREUENT OF CROWN WIDTH (93 per eent probablity)

| Standard of accuracy (feet) | Pine | Spruce and Fir | Hatiwoods |
| :---: | :---: | :---: | :---: |
| $\pm 3$ | repect | reject | reject |
| $\pm 4$ | accept | recect |  |
| $\pm 5$ | accept | reject |  |
| $\pm 6$ |  | accept | repeet |

conifers growing in dense clumps. The width of crowns of irregular form is very difficult to measure in the field, and on photographs a considerable portion of crowns of trees growing close together is not visible.

Because the accuracy of the ground measurements is doubtful, an evaluation of photo measured crown width might better be based on the consistency with which it is measured and by the extent to which it contributes to the estimate of a tree's volume or quality.

## Stem Diameter

Even when photographs are taken in the winter the measurement of diameter at breast height is not practical on verticals because too often the trunk is hidden by the tree's crown or by other trees. On the three photo plots used for the diameter tests it was rarely possible to measure d.b.h. directy, but more frequently the width of a tree's shadow could be measured. A brief test was therefore carried out to see how accurately diameter at breast height could be determined from shadow measurements. The width of the shadow of the section of the bole $4 \frac{1}{2}$ feet above ground was measured and d.b.h. was then determined; later the d.b.h. of the trees involved was measured in the field.

The results of the measurements of d.b.h. from shadow images are summarized in Tables 5 and 6 .

TABLE 5-MEASUREMENT OF D.B.M.

| Regression equation*: $\mathbf{X}=$ | $-0.570+1.049 x$ |
| :---: | :---: |
| Meat feld measurement (inches) | 13.07 |
| Mean photo measurement (inches). | 13.15 |
| Difference (inches) | 0.08 |
| Standard error of estimate (mohes) | 0.89 |
| Number of measurements. | 34.00 |

* $X$ is the photo measurement and $X$ the feld measurenent

TABLE 6-STANDARDS OF ACCORACY REACLET IN TUE MEASUREMENT OF D.B.H. (6) per cent probability)

| Standard of Accuracy (inehes) | reject |
| :---: | :---: | :---: |
| $\pm 1.0$ | acecpt |
| $\pm 1.5$ | accept |

Although the photo-estimated diameters are accurate in this test one should not conclude that satisfactory diameter measurements can always be obtained, because a number of unpredictable factors may influence the results Although tree shadows may appear very clearly on large-seale photographs, large errors can occur if a stem's diameter is determined from a measurement of its shadow because one camot see, on the photograph, where the penumbra meets the full shadow, nor can one determine how much of the penumbra is resolved on the photograph. The penumbra therefore cannot be ignored for diameter measurements, as it could be for height measurements (Figure 4).


Figure 4. Both shadows, although of unequal width, are cast by eyindrical rods of 0.9 inch diameter. Shadow $: 4$ A cast by the part of the rod near the ground, Shadow at B cones from the portion of the rod 4 feet above ground.

## Example:

With the sun at $30^{\circ}$ altitude the width of the shadow cast by the section of the stem that is 20 feet above the ground equals the true stem diameter $\pm 5$ inches. The error is +5 inches if the penumbra is added to the full shadow; it is -5 inches if the penumbra is ignored (if the stem diameter is less than 5 inches, there is no full shadow). For d.b.h. the corresponding error is a little more than $\pm 1$ ineh; considerably smaller, but still significant.

On winter photographs the problem is further aggravated by irradiation and halation, which may partly destroy a photographic image when the contrast between light and dark objects is great. Light striking the photographic film is seattered by particles in the emulsion and by the back of the film; it will therefore spread into zones of the film that should have remained in darkness; bright areas expand at the expense of dark objects; branches and tree trunks and their shadows are obliterated or appear too thin. Consequently the smaller branches that are so important for the identification of hardwoods are often lost, and if one attempts to measure stem diameters, underestimates will result; in extreme cases the image of a stem or its shadow may be completely wiped out (Figure 5).


Figure 5. Tree shadows, which show up clearly against the dark road, are obliterated where they fall on snow in the lower portion of the photograph.

## Tree counts

TABLE 7 -SUMMARY OF TREE COUNTS (trees over 20 ft . high)

|  | Pines | Spruce and Fir | Mardwoods | All Species |
| :---: | :---: | :---: | :---: | :---: |
| Photo Count. | 109.0 | 178.0 | 153.0 | 440.0 |
| Field Count. | 111.0 | 197.0 | 1.70 .0 | 4.88 .0 |
| Difference. | $-2.0$ | $-19.0$ | $-17.0$ | $-38.0$ |
| Per Cent Missed. | 1.8 | 9.6 | 10.0 | 7.9 |

The fact that even at such a large scale an average of 7.9 per cent of all trees was missed is not discouraging if one considers that it was mostly the small trees that were not seen. The extent to which this was the case is illustrated by Figure 6; well over one-half of the trees missed fell in the 4 -inch d.b.h. class and large trees were counted with satisfactory accuracy. For example, no trees were missed in three plots that were located in stands of tall pines; on the other hand many errors were made in two plots that contained a dense understorey of balsam fir, spruce and tolerant hardwoods, which were overtopped by a few big trees.

It appears that an accurate count of trees in the understorey is impossible, but the count of big trees is, for practical purposes, a complete one.


Figure 6. The distribution, by diameter classes, of the number of trees missed while counting trees on air photos.

## Species identification

When trees were classified into species groups (pines, spruce and fir, and hardwoods) 97.7 per cent of all trees that could be seen on the photograph were placed into the right category. However, when it was attempted to identify individual tree species only 72.7 per cent of all trees were correctly identified.

An examination of the mistakes made showed that, just as in the case of tree measurements, the greatest difficulty was again caused by the small trees; 33.3 per cent of the errors were made in attempting to separate small balsam fir and small spruce, and 27.5 per cent when small maple and small hornbeam trees were confused. These are not errors of serious consequence; tall coniferous trees were identified with very few mistakes. White pine trees that were in the advanced stages of blister rust were recognized by their very thin foliage.

While leafless deciduous trees can often not be identified by species at scales smaller than 1:1:200, that seale is adequate for their identification. Increasing the scale of photography allows more successful species identification, but it is doubtful that the increase in accuracy justifies the increase in cost. On winter photographs recently taken at $1: 600$ there was no difficulty in separating small spruce and small balsam fir, but small hornbeam and maple could still not be recognized. Species identification at large scales such as $1: 1,200$ is based almost entirely on branching habit and crown characteristics with far less emphasis on such indefinite or unreliable characteristics as site, association, and photographic tone and texture, that are so important when interpreting species on photographs of smaller scales.

Results obtained by the U.S. Forest Service show that colour photography improves the speed as well as the accuracy of photo interpretation. In those seasons of the year when deciduous foliage is present colour photography will undoubtedly prove an advantage. However, winter photographs taken with colour film will not be much more useful than panchromatic photos for identifying species. A few $1: 1,200$ winter colour photographs which were taken in conjunction with the experiment did not appreciably improve the ability to recognize species, although some hardwoods could be identified by the colour of their bark; for example, trembling aspen with its greyish-green bark could be distinguished from largetooth aspen, the bark of which has an orange hue.

Undoubtedly some deciduous tree species will be more easily recognized on photography taken when they are in leaf especially in the late spring, the early summer or in the fall, when there are many species differences brought about by phenological changes (Sayn-Wittgenstein, 1961). But taking photographs at those seasons, involves sacrificing the ability to measure or inspect the trunks of many trees because they are obscured by foliage. Under special circumstances it may therefore be justified to take two sets of photographs-one before, and one after leafing.

## Scale determination

The scale of photography was determined by radial line ploting with an accuracy that is probably acceptable, but could nevertheless be significantly improved. As a check of scale the distance between several points on the radial line strip was measured and compared with the corresponding distance as measured on the ground, with the following result:

| Distance on madial line | Distance by ground <br> measurement (ft.) | Per cent error |
| :---: | :---: | :---: |
| 130.6 | 129.2 | +1.1 |
| 167.3 | 170.8 | -2.1 |
| 174.4 | 182.0 | -4.2 |
| 467.8 | 478.0 | -2.1 |

Because the necessary control points are often not avalable, radial line plotting may frequently prove unsatisfactory for determining the scale of largescale sampling photographs. A more accurate and faster method should be developed, perhaps by pursuing Avery's approach of using a fixed beam between two cameras or by employing more accurate altimeters and range finders, or perhaps an air profile recorder.

A 12-inch foeal length lens has proved more satisfactory for scale determination than a 4 -inch lens, because the longer focal length has reduced the distortions due to tilt and has lessened the effect of differences in flying height above ground that exist due to the changing terrain. With cameras of long focal length, large seales of photography are obtained by flying at a greater altitude and consequently a given change in flying height is a smaller fraction of the total flying height and has less effect on photographic seale.

Furthermore, the problem of tilt may be reduced by flying at higher altitudes, for there the air is usually less turbulent; also for a given degree of tilt, the resulting distortions of the terrain will be larger for short focal length lenses than for long focal length lenses. However, the ability to make accurate parallax moasurements deteriorates with increased flying height and the use of long focal length lens therefore has its disadvantages. But, with a 12 -inch lens and a seale of 1:1:200 the reduction in parallax was not important.

## SUMMARY

Panchromatic winter photographs at a scale of 1:1,200 were taken with a Vinten 70 mm . camera employing a 12 -inch focal length lens and a shutter speed of $1 / 2,000$ second. Sample plots, equivalent to $1 / 5$-acre on the ground, were established at the centre of ten photographs that were chosen at random; and trees on these plots were counted, identifed, and their height, crown width and d.b.h. were measured.

Large trees were accurately counted and identified, but difficulties were encountered with the small ones. With a probability of 95 per cent the photomeasurement of the height of conifers differed by less than 6 feet from the ground measurement, and the height of hardwoods by less than 7 feet. The corresponding figures for the measurement of crown width were 4 feet for spruce and fir, 5 feet for the pines and 6 feet for hardwoods. For some trees it was possible to determine diameter at breast height by measuring the width of the stems shadow on the photograph. The photo-measured diameter differed by less than 1.5 inches from the ground measurement, with a probability of 95 per cent.

The results indicate that such photographs may allow the determination of the volume of individual trees and stands if precise enough equations for volume based on species, crown width and height can be derived. But several improvements have to be made before large-seale photographs can be put to practical use. In particular, a faster and more accurate method of determining photographic scale is required. The 12 -inch focal length lens has given better results for scale than a previously tested 4 -inch lens, but radial line plotting which was used is slow and requires ground control that is often not available.

## SOMMAIRE

Des photographies à l'échelle de 1:1,200 sur film panchromatique, ont été prises en hiver à l'aide d'une caméra Vinten 70 mm , munie d'un objectif à focale de 12 pouces et d'un obturateur au $2000^{\circ}$ de seconde. Des places échantillons d'une superficie de $\frac{1}{5}^{\frac{10}{e}}$ d'acre ont été délimitées au centre de dix photos prises au hasard; sur photo, on a compté et identifié les arbres, et on a aussi mesuré le diamètre des houppiers et le DHP des trones.

On est parvenu à compter et à identifier exactement les arbres de grande taille, mais on a éprouvé de la difficulté lorsqu'il s'est agi d'arbres de petite taille. Dans 95 p. 100 des cas, les mesures prises sur photo de la hauteur des conifères ne differaient des mesures prises au sol que de moins de 6 pieds, et celles des feuillus, de moins de 7 pieds. Les mesures de diamètre des houppiers étaient inexactes à raison de 4 pieds dans le cas des épinettes et des sapins, de 5 pieds dans le cas des pins et de 6 pieds dans le cas des feuillus. On est parvenu à déterminer le DHP de certains arbres en mesurant sur photo la largeur de l'ombre projetée par les fûts. Le diamètre déterminé d'après une photo différait de moins de 1.5 pouces du diamètre mesuré au sol, et ce dans 95 p. 100 des cas.

Les résultats indiquent qu'il est possible, grâce à ce genre de photographie, de déterminer le volume sur pied des arbres et même de peuplements, pourvu qu'on soit en possession d'équations exactes établies à l'aide des facteurs essence, diametre de houppier et hauteur. Toutefois, il reste à amélorer la méthode si l'on veut se servir de photos à grande échelle. Il faudrait surtout mettre au point une méthode plus rapide et moins sujette à erreurs, pour déterminer l'échelle exacte de la photo. L'objectif à focale de 12 pouces a donné de meilleurs résultats, quant à l'échelle des photos, que l'objectif à focale de 4 pouces dont on s'était servi auparavant; mais la méthode d'échantillonnage radial qu'on a suivie est plutôt lente, et elle exige des données de vérification au sol qu'on ne possède pas toujours.

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