FIXED AIR-BASE 70 mm PHOTOGRAPHY, A NEW TOOL FOR FOREST SAMPLING

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INTRODUCTION

Two basic approaches have been made in the field of ultra large scale forestry photography.

One approach uses standard photographic and photogrammetric techniques with single camera, timed-interval photography from fixed wing aircraft. This approach has been well documented by Seely (1962), Sayn-Wittgenstein (1962) and Kippen and Sayn Wittgenstein (1964). It is faced with three major problems; namely, the determination of photo scale, the elimination of differential tilts between successive photos, and the effect of wind sway on parallax measurements, Aldred (1964).

The other approach, and the one to be discussed in this paper, is fixed air-base photography from helicopters. This method, because it successfully eliminates the problems of scale determination, differential tilts, and wind sway errors, appears to hold the most promise for application in the field of forest sampling.

Avery (1959) using two Rolliflex cameras on a four foot hand held boom took stereo pairs of photos of samples. Using ground control of each pair of photos as the basis for photo scale, this method overcame the problems of differential tilts and wind sway.

The writer, Lyons (1961 and 1964), has developed Avery's method further by the simultaneous firing of first, two F24 cameras, and later two Hulcher 70 mm cameras mounted one at each end of a 15 foot boom suspended longitudinally beneath a Bell 47G-2 helicopter (Figure 1). Flying height and photo scale for this type of photography are determined from the photo measurement of the 15 foot air base. Wind sway is eliminated because both cameras are fired instantaneously, and differential tilting between photographs is eliminated because the two cameras maintain a fixed orientation with each other.

In the time allotted for this subject, it will not be possible to discuss in detail all of the experiments and their results; therefore the purpose of this paper will be to summarize the results of early and recent experiments and make an attempt to suggest future applications of the method.

PHOTO SCALE DETERMINATION

Early studies, using F-24 cameras and later confirmed by Hulcher 70 mm cameras and more recently by Linhof aero-electric 70 mm cameras, developed

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the flying height regression of $I/H = b_0 + b_1 pb$ where I/H is the reciprocal of flying height in feet and pb is the photo measurement of the 15 foot air-base in inches. The calibration procedure for the assembly is described by Lyons (1961).

The precision of the flying height regression for F-24 and Hulcher photography is approximately $\pm 3\%$ at a flying height of 300 feet. Linof photography gives a precision of $\pm 1\%$ at 300 feet. These regressions are sufficiently precise for the determination of tree heights, crown widths and log dimensions.

Both the F-24 cameras and Hulcher cameras have focal plane shutters which are difficult to synchronize. The Linhof cameras have between lens sector shutters which are easily synchronized and this explains the improvement in the flying height precision produced by them.

TREE MEASUREMENTS

For interpretation, contact-scale film positives are viewed with transmitted light (Figs. 2-5). Tree heights are measured with an Abrams height finder and crown widths are measured with a scale calibrated to 1/100 of an inch.

$$\text{The heights are computed using the formula } h = \frac{H^2 dp}{H dp + f B}$$

where: h = Tree height — feet

H = Flying height above ground — feet

dp = Differential parallax — mm

f = Camera lens focal length — mm

B = Air-base — 15 feet

In the Okanagan Public-sustained Yield Unit, 394 trees of various species and ranging in height from 50 to 150 feet were compared. The mean aggregate difference and standard error of the photo minus felled measurements was $+0.10 \pm 2.87$ feet. These same trees were also measured standing, with chain and abney, and yielded an abney minus felled difference of $+0.56 \pm 4.34$ feet. Photo measurements of tree heights appear to be superior to chain and abney measurements.

328 trees in the Yale Public Sustained-yield Unit were also compared. The mean aggregate difference and standard error, of photo minus felled heights, were -1.3 ft. $+4.3$ ft. The average tree heights were 120 feet and ranged from 70 to 190 feet. The increased error in tree heights in the Yale area was expected because of the increase in tree size and ground slope.

Crown widths were measured at a point as close as possible to one-half way between the base and top of each tree. Measurements were taken at right angles to a photo radius, and the crown widths were compiled using the formula $CW = \frac{(H - \frac{1}{2}h)(cw)}{f}$ where

$$\begin{aligned} CW &= \text{Crown width in feet at } \frac{1}{2} h \\ H &= \text{Flying height above ground in feet} \\ cw &= \text{Crown width at } \frac{1}{2} h \text{ in inches} \\ h &= \text{Tree height in feet} \\ f &= \text{Camera focal length in inches} \end{aligned}$$

The crown widths were not compared with ground measurements, but were used with some success in computing tree volumes and diameters.

TREE VOLUME COMPUTATION

Single tree volume regressions were computed for six Interior species and five Coast species, relating ground whole stem gross volume (from B.C. Forest Service Standard Volume Tables 1962) to photo measured tree height and crown width. Stocking and a decadence factor were also tested but were dropped because they did not significantly reduce variance.

Table 1 lists the equation form and the regression constants and errors. Wherever there are more than 100 trees as a basis for a table the residual coefficients of variation are of the order of 20 to 40 percent. This is substantially higher than conventional volume tables, but by no means unworkable when cost differentials are considered.

TREE DBH COMPUTATION

The same IBM Programme used to produce tree volume equations was also used to produce tree dbh equations. In this case tree dbh as measured on the ground was the dependent variable. Table 2 lists the dbh equation statistics.

TABLE 1
VOLUME EQUATIONS FOR INTERIOR SPECIES, F, B, S, PL, PY, L AND
COAST SPECIES F, C, H, B, CY
Equation Form: $1 + \log V = b_0 + b_1 (1 + \log h) + b_2 (1 + \log CW)$

Species	b_0	b_1	b_2	SE%	R ²	Basis
Interior F	-4.168168	+2.437491	+0.822429	±40.6	0.86	346 trees
B	-2.931942	+1.972530	+0.513830	±26.3	0.82	141 "
S	-4.305651	+2.743935	+0.447837	±26.8	0.88	318 "
Pl	-4.034879	+2.586217	+0.431874	±24.2	0.78	273 "
Py*	-3.760667	+2.036748	+1.180889	±68.5	0.73	39 "
L*	-0.827920	+3.798102	+0.714703	±33.9	0.92	52 "
Coast F	-3.937913	+2.353281	+0.770398	±35.2	0.86	140 "
C*	-4.777561	+2.667759	+1.146943	±84.4	0.87	68 "
H	-3.893500	+2.563048	+0.519351	±42.6	0.90	329 "
B	-4.064029	+2.639853	+0.533690	±37.0	0.94	408 "
Cy*	-3.161581	+1.664802	+1.331168	±50.4	0.60	34 "

* Insufficient trees.

SAMPLE VOLUME COMPARISONS

On the 23 Interior samples the whole stem gross sample volumes of all trees 7.1 inches plus, determined from ground measurements and standard volume tables, were compared with the whole stem gross sample volumes

determined from the photo measurements and photo volume tables. Photo volumes of individual trees 7.1 inches plus were recorded or rejected on the basis of d.b.h. computed from photo d.b.h. tables.

The mean volumes of the 23 paired ground and photo samples are $5,126 \pm 2,038$ cu. ft. per acre and $4,780 \pm 2,036$ cu. ft. per acre respectively, with a mean aggregate difference of -346 ± 418 cu. ft. per acre. The mean aggregate difference is significant at P.01; $t = 3.97$, and the difference between variances is not significant at P.05; $F = 1.002$.

In order to determine the reliability of the photo method to predict volumes of portions of Interior stands, a further comparison was made of ground

TABLE 2

D.B.H. EQUATIONS FOR THE INTERIOR SPECIES F, B, S, PL, PY, L AND
COAST SPECIES F, C, H, B, Cy

Equation form: $1 + \text{Log DBH} = b_0 + b_1 (1 + \text{Log } h) + b_2 (1 + \text{Log } CW)$

Species	b_0	b_1	b_2	SE%	R^2	Basis
Interior F	-0.775880	+0.729490	+0.455304	± 20.8	0.73	346 trees
B	-0.213751	+0.531832	+0.264801	± 11.3	0.61	141 "
S	-0.889605	+0.914648	+0.229799	± 13.1	0.79	318 "
Pl	-0.725780	+0.812172	+0.223819	± 11.8	0.61	273 "
Py*	-0.473410	+0.490698	+0.596072	± 30.2	0.58	39 "
L*	-2.152088	+1.450560	+0.372102	± 16.4	0.88	52 "
Coast F	-0.675071	+0.686391	+0.448243	± 19.3	0.71	140 "
C*	-1.364369	+0.971722	+0.641396	± 42.0	0.79	68 "
H	-0.639524	+0.809471	+0.260188	± 21.2	0.77	329 "
B	-0.771251	+0.858860	+0.265664	± 18.0	0.87	408 "
Cy*	-1.124458	+0.648939	-0.299189	± 25.0	0.51	34 "

* Insufficient number of trees.

determined whole stem gross volumes of all trees 7.1 inches to 11.0 inches, and photo determined whole stem gross volumes 7.1 inches to 11.0 inches. The selection of photo volumes was again based on photo determination of tree d.b.h.'s.

The mean whole stem gross volumes 7.1 inches to 11.0 inches d.b.h. from ground and photo measurements are 955 ± 929 and $988 \pm 1,090$ cu. ft. per acre respectively with a mean aggregate difference of $+33 \pm 310$ cu. ft. per acre. The mean aggregate difference is not significant at P.05; $t = 0.51$, and the difference between variances is also not significant at P.05; $F = 1.38$.

From these two comparisons we can assume that in the Interior, photo methods are as useful as ground methods in predicting the whole stem volume of all trees 7.1 inches d.b.h. and over, and all trees 7.1 inches to 11.0 inches, although there may be consistent aggregate differences to contend with.

On the 24 Coast samples, similar comparisons were made. On these samples, due to present inventory requirements, it was not possible to compile the ground samples for whole stem gross volume 7.1 inches d.b.h. and over. The

ground volumes were compiled to Forest Service inventory standard 7.1 inches plus, close gross; which means whole stem gross less the volumes of one foot stumps and tops above diameters inside bark of 4 inches. The close gross 7.1 inches plus ground volumes were compared with the whole stem gross 7.1 inches plus photo volumes. A comparison was also made between the close gross 7.1 inches to 11.0 inches ground volumes and the whole stem gross 7.1 inches to 11.0 inches photo volumes. In these comparisons, photo volumes were again recorded or rejected on the basis of the photo determinations of tree diameters.

The mean gross volumes 7.1 inches and over of the 24 paired ground and photo samples are $12,833 \pm 4,771$ cu. ft. per acre and $11,865 \pm 4,670$ cu. ft. per acre, with a mean aggregate difference of $-968 \pm 2,044$ cu. ft. per acre. The mean aggregate difference is significant at P.05; $t = 2.32$, and the difference between variances is not significant at P.05; $F = 1.04$.

The mean gross sample volumes 7.1 inches to 11.0 inches of the 24 paired ground and photo samples are 567 ± 481 cu. ft. per acre and 160 ± 139 cu. ft. per acre, with a mean aggregate difference of -407 ± 386 cu. ft. per acre. The mean aggregate difference and the difference between variances are both significant at P.01; $t = 5.16$ and $F = 12.00$.

By correcting the photo sample volumes for consistent differences using the regression $V_c = +112.4 + 2.52 V_p$, the following comparison between the 24 pairs of ground close gross sample volumes 7.1 inches to 11.0 inches and corrected photo whole stem gross sample volumes 7.1 inches to 11.0 inches shows means of 567 ± 481 and 566 ± 366 cu. ft. per acre for ground and photo respectively, and a mean aggregate difference of -1 ± 312 cu. ft. per acre. The difference between means and variances are not significant at P.05; $t = 0.01$ and $F = 1.31$.

It can be assumed therefore that by using photo methods with corrections for consistent errors, it will be possible to predict gross stand volumes by species, as precisely as by using standard ground methods. This will hold for whole stands or portions of stands.

COST COMPARISONS

The approximate cost of a standard Forest Service ground sample is \$100.00 and of an equivalent photo sample \$15.62. These costs include all material, transportation and measurements costs.

(a) Simple Sampling

Considering simple sampling schemes, photo sampling to completely replace ground sampling, to provide only gross volumes by species, the cost comparison for the same precision of estimate can be based on the variance ratio between the two methods.

The variance ratio in the Interior is 1.0024 in favour of the photo method. The cost of a photo only survey in the Interior would therefore be 15.6 percent of a ground survey.

The variance ratio on the Coast is 1.04 in favour of the photo cruise and therefore the cost of a photo only survey on the Coast would be 15.0 percent of a ground survey.

Of course, photo volume tables must be available for local conditions to take advantage of this large cost advantage.

(b) Double Sampling

The following double sample analysis is based on the assumption that there will be the optimum ratio of ground and photo samples. The base costs are the same as for the simple sample comparison excepting that the cost of ground control samples is \$70.00 instead of \$100.00 because the control samples are selected on the basis of accessibility. From Cochran (1953) the optimum ratio

$$\frac{n_g}{n_p} = \frac{\text{number ground control samples}}{\text{number photo samples}} = \sqrt{\frac{\overline{Sv_g^2}}{\overline{Sv_p^2}}} \times \frac{\text{Cost photo sample}}{\text{Cost ground control sample}}$$

for an equal sampling error:

$$\frac{n_p}{n_s} = \frac{\text{number of photo samples}}{\text{number of standard samples}} = \frac{1-r^2}{n_g} \times \frac{\overline{Sv_s^2}}{\overline{Sv_p^2}}$$

The cost ratio:

$$\frac{\text{Cost double sample method}}{\text{Cost standard sample method}} = \frac{C_{pg}}{C_s} = \frac{n_g C_g + n_p C_p}{n_s C_s}$$

In the Interior, $n_s = 1.000$, $n_g = 0.564$, $n_p = 1.192$. The cost of the double sample method is 58 percent of the cost of the standard sample method. On the Coast, $n_s = 1.000$, $n_g = 0.401$ and $n_p = 1.730$ and the cost of a double sampling method is 55 percent of a standard sampling method. The cost comparisons shown are substantially in favour of the photo methods. It is interesting to note that even with the larger errors in measurement and volume equations on the Coast, the cost comparisons are essentially the same as the Interior comparisons. The advantage of double sampling as compared to simple sampling is that the double sample will provide the sophisticated answers presently available with standard ground cruising.

Residue Studies

Using 70 mm stereo pairs, piece counts and dimension measurements of logging waste have proven to be very accurate.

On a ten chain transect line established on the ground in a Coast logged setting, all pieces over four feet long and 4.0 inches and larger at the small end, were counted, and the lengths and diameters of every fifth piece were measured. In all 155 pieces of qualifying material were counted and the dimensions of 32 pieces were measured.

The transect was photographed from a flying height of 90 feet and three interpreters made counts of qualifying pieces crossing the transect and measurements of the end diameters and lengths of the same pieces as measured on the ground (Figure 6). All three interpreters counted 151 qualifying pieces of

material crossing the transect line. Table 3 shows the comparison of the three photo interpreters with the ground measurements.

TABLE 3
PHOTO MEASUREMENTS OF 32 LOGS MEASURED BY THREE INTERPRETERS
COMPARED WITH GROUND MEASUREMENTS

	Mean Diameter Inches	Mean Length Feet	Mean Volume Cu. Ft.
Ground	8.50 $\pm$ 3.07	26.11 $\pm$ 12.80	10.47 $\pm$ 10.08
Interpreter 1	8.93 $\pm$ 2.93	25.12 $\pm$ 12.26	10.50 $\pm$ 9.41
Interpreter 2	8.49 $\pm$ 2.90	25.30 $\pm$ 12.94	9.71 $\pm$ 9.35
Interpreter 3	8.42 $\pm$ 2.98	25.56 $\pm$ 12.14	9.68 $\pm$ 8.88

Regression analysis showed that for all three interpreters the slope b , of the regression was not significantly different from one at P.05, indicating no consistent errors between the three interpreters and ground measurements. It is possible therefore, with fixed air-base photography and small constant corrections, to count and measure the dimensions and gross volumes of pieces of logging waste as precisely as they can be counted and measured on the ground.

Eight 1/10 acre plots were established in an Interior spruce-balsam logged area (Figure 7). Ground measurements included the diameters and lengths of pieces of qualifying material within the boundaries of the plots. If a piece of qualifying material straddled a plot boundary only the included portion was measured. Photo measurements were the interpretation and measurement of all included qualifying material in the eight plots. Interpreters two and three each measured one half of the plots.

Mean ground and photo volumes were 3,663.7 $\pm$ 819.0 cu. ft. per acre and 3,306.2 $\pm$ 996.9 cu. ft. per acre respectively and a mean aggregate difference of -357.4 $\pm$ 340.1 cu. ft. per acre. The mean aggregate difference is significant at P.05 but there is no significant difference between variances at P.05. The regression coefficient b , is also not significantly different from one at P.05, indicating constant underestimates in photo measurement.

SUMMARY

This has been a very brief summary of the experiments and results of the use of 70 mm helicopter fixed air-base photography for forest sampling. A more detailed description of the experiments and their results is shown in a paper by the writer presently awaiting publication, Lyons (1966). Details of the logging residue studies have been published by Ingram (1966).

In summary, the analysis of the results of present experiments shows several things:

1. Tree heights, both of tall and short timber, in dense and open stands and on gentle and steep slopes, can be measured accurately on 70 mm stereo pairs; standard errors of ± 3 to 4 feet. These errors are smaller than can be expected from standard ground measurements by chain and abney. Wind sway is no problem because both pictures are taken at the same instant.
2. Workable, single tree volume tables, based on photo height and crown width can be developed for the major coniferous species of British Columbia.
3. Workable, single tree dbh tables, based on photo measured height and crown width can be developed for the major coniferous species of British Columbia.
4. On the basis of 23 double samples in the Okanagan P.S.Y.U. and 24 double samples in the Yale P.S.Y.U.:
 - a) There is no significant difference between ground and photo methods for determining mean stand gross volumes of trees 7.1 inches plus.
 - b) There is no significant difference between ground and photo methods of predicting mean stand gross volume of portions of stands such as 7.1 inches to 11.0 inches dbh.
5. Cost advantages of the photo method are exceedingly strong; e.g. photo only sample schemes for gross volume by species 7.1 inches plus are 15 to 15.6 percent as expensive as standard ground methods. Double sample schemes providing equally sophisticated answers as standard ground methods with an optimum ratio of ground and photo samples, are between 55 and 58 percent as expensive as standard ground methods.
6. The above results indicate that the 70 mm fixed air-base photo method of forest sampling is definitely feasible in British Columbia and warrants further development.
7. The preliminary analysis of the residue study samples indicates that photo methods are essentially as good as ground methods for the determining of diameters, lengths and gross volumes of individual pieces, and the gross volumes of plots.
8. With improved cameras and measuring equipment, it is the writer's considered opinion that errors and costs of the present 70 mm photo method can be reduced significantly.

Further studies involving the use of colour films, camouflage detection films, infra red films, and various filter combinations are planned, in the hope that they may show the presence, and possibly extent of decay in individual trees.

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FIGURE 1. Hulcher 70 mm cameras on boom beneath Bell 47-G2 helicopter.

FIGURE 2. Two films being viewed through Abrams pocket stereoscope with attached height finder.

FIGURE 3. Amabilis fir western hemlock type in Yale P. S. Y. U. The heights range from 160 to 190 feet. Photo scale 1:1364.

FIGURE 4. Western red cedar type in Yale P.S.Y.U. Tree heights range from 150 to 170 feet. Photo scale 1:1276.

FIGURE 5. Douglas fir, western red cedar, western hemlock type in Yale P.S.Y.U. Tree heights range from 130 to 160 feet. Photo scale 1:1261.

FIGURE 6. Logging waste, Yale P.S.Y.U., after high lead logging in type similar to figure 5. Waste composed of cull logs and material smaller than present logging standards. Photo scale 1:373. Note the tape-marked transect line.

FIGURE 7. Logging waste in Interior spruce balsam type after "cat" logging. Note the tape marking out line of 1/10 acre square plots with transect line through the centre. Photo scale 1:750.