wave-lengths can be utilized without introducing loss of detail. It is entirely possible that high quality absorption-type color filters might be used to produce better photography for forestry purposes, but probably not without a film exhibiting a greater degree and range of sensitivity than that of those currently available.

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Comparative Usefulness of Three Parallax Measuring Instruments in the Measurement and Interpretation of Forest Stands

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ABSTRACT: *The accuracy and efficiency of three simple height-measuring devices are evaluated for forestry use. Records of measurement and elapsed time of five photo interpreters who used these height-finding instruments in measuring forest stands were analyzed in the study.*

INTRODUCTION

DURING recent years, foresters have become increasingly interested in the measurement of tree and stand height by parallax, and in the accuracy of this measurement. Parallax-bars have been compared to parallax-wedges, and both of these to more elaborate measuring devices; usually the differences in accuracy have been found to be nonsignificant. These comparisons have led some forest photo interpreters to assume that any third-order device capable of measuring parallax difference on contact prints is suitable for measuring forest plots, and that selection is largely a matter of personal preference.

The study reported herein, recently completed at the Intermountain Forest and Range Experiment Station, was designed to test the relative value of three photo height-finding devices in routine measurement of forest inventory plots.

EARLY TESTS

Many of the earlier tests were made using height measurements of single trees under conditions rarely experienced by photo interpreters in forest inventory. Spurr (5) states that errors in measurement of individual tree heights by parallax-wedge ranged from 3 to 20 feet on 1:15,840-scale photos of the Harvard Forest. Losee (1) obtained systematic errors of −10 to −16 feet in heights of conifers estimated by a floating-dot parallax device on 1:7,200-scale photos. Worley and Landis (6), using repeated measurements on individual trees made by parallax-wedge and parallax-bar, found no significant difference in the 8- to 10-foot standard errors of estimate obtained by using these two instruments. They stated, however, that interpreters using the parallax-bar seemed to underestimate heights of larger trees to a greater extent than those who used the parallax-wedge.

Studies made using stand measurements by parallax-wedge on randomly distributed 1-acre sample plots have recorded mean errors of 6 to 10 feet on 1:20,000-scale photos of eastern hardwood stands (4), and standard errors of estimate of 5 to 11 feet on 1:20,000- to 1:30,000-scale photos of conifer stands in the Rocky Mountains (2). These studies considered stand measurements by parallax-wedge only; no comparable measurements were made by parallax-bar or other floating-dot device.

Both in forest inventory and in direct photo estimates of volume, photo interpretation of sample plots often requires measurement of crown-diameter and crown-coverage

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as well as the measurement of stand height. In selecting an instrument, differences in the time required and in the ease of making all necessary measurements, may be factors almost as important as the relative precision of the measurements made. This is particularly true where the expected standard error of estimate for height measurements seems to indicate that the critical factors in accuracy are the eyesight and experience of the interpreter. When a parallax-measuring device used for measuring height tends to complicate or unduly retard the entire process of sample plot measurement and interpretation, it may prove to be an undesirable instrument for forest inventory regardless of its relative precision.

Instruments Used in This Study

The new MANUAL OF PHOTOGRAPHIC INTERPRETATION[1] describes several height-measuring instruments used under lens or mirror stereoscopes as well as several direct-viewing plotters[2] that can be used to measure spot heights. Any of these could be used by a forest photo interpreter in measuring stand heights. However, foresters have generally favored the simple, less costly devices, such as the parallax-wedge or the parallax-bar, designed for use under the common lens stereoscope. Initial cost has been an item, but these simple devices are popular largely because they are easy to use, yet adequately precise. They require little space, are readily used on an office desk, and are easily transported.

[1] Published in 1960 by the American Society of Photogrammetry.

[2] Used directly over photographic prints, as contrasted to the much larger projection-type photogrammetric instruments.

The three height-measuring instruments described below are available at Intermountain Station for use in training photo interpreters. The first two are commonly used in forest photo interpretation. The third, currently obtainable as Armed Services surplus, was secured as a possible device for measuring stand height.

1. *Parallax-wedge.*—This long wedge printed on transparent film (Figure 1) was designed for use on photos of mountainous areas, and can measure parallax differences up to 1.0 inch to the nearest 0.002 inch. The parallax-wedge, using the floating-line principle and designed for use with a lens stereoscope, is the simplest and cheapest of all height-finding instruments.

2. *Abrams Height Finder.*—This small size parallax-bar (Figure 2) was designed for use with CF-8 and CB-1 Abrams lens stereoscopes, and can measure parallax differences up to 20 mm. (0.79 inch) to the nearest 0.01 mm. (0.0004 inch). Its total traversing range is approximately 22.5 mm. (0.9 inch). In use, it clips onto the legs of these Abrams scopes, but can be operated under other makes. Like all other parallax-bars and most stereo plotting instruments, its operation is based on the floating-dot principle. Two small transparent plates, each with a fine dot in the center, are mounted on a bar that allows

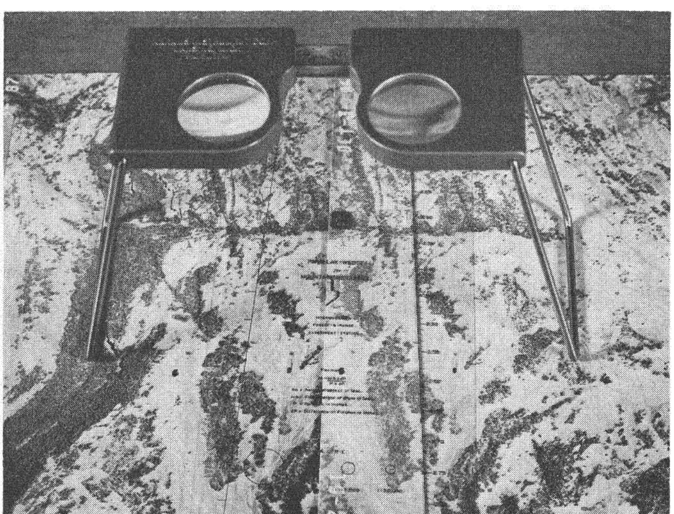

FIG. 1. Parallax wedge, printed on film, is based on the floating line principle, and is easily moved aside when other measuring devices must be used. Its initial cost is about $1.

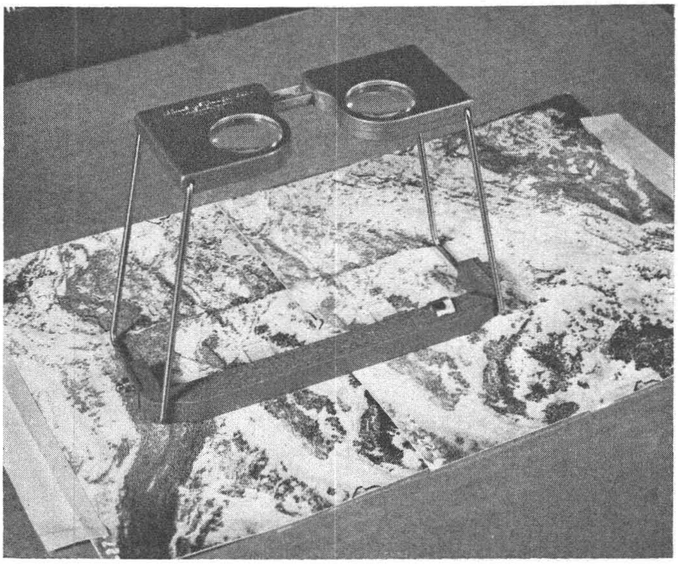

FIG. 2. Abrams height finder, based on the floating dot principle, is the simplest and most compact of the parallax bars. It is clipped to the legs of the stereoscope. The use of other measuring devices usually requires a second stereoscope. Its initial cost is $50 to $60.

lateral movement of a right-hand plate. The distance of movement is controlled and measured by a small micrometer wheel.

3. *Austin Photo Interpretometer.*—This instrument (Figure 3) consists of a lens stereoscope together with a base having two movable transparent plates on which is printed a series of scales and fine dots. The right-hand (X) plate moves laterally; this movement is controlled and measured by a micrometer wheel having a double dial graduated in both feet and millimeters. The left-hand (Y) plate moves at right angles to the (X) plate and can be adjusted to remove (Y) parallax. The micrometer dials are graduated to 0.00005 foot (0.0006 inch) and 0.02 mm. (0.0008 inch). Although the entire traversing distance is only 0.005 foot, a series of dots on the left-hand plate allows measurements up to 0.05 foot (0.6 inch). Operation of this instru-

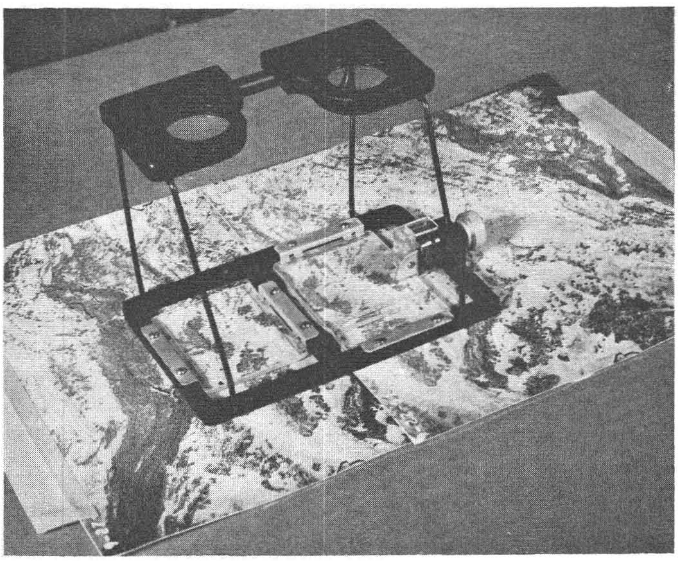

FIG. 3. The Austin photo interpretometer is a more complex instrument based on the principle of the floating dot. An integral part of the stereoscope, the large glass plates require use of a second scope when other measuring devices are used. Available as war surplus, its price is about $40.

ment also is based on the principle of the floating dot.

Objectives

In general, the desire was to learn whether significant advantages or disadvantages were inherent in using any one of these three parallax-measuring devices when the entire job includes other measurements and interpretations. The study was designed to provide answers for these three specific questions:

1. Do measurements by these three instruments differ significantly in the accepted indices of relative accuracy? These indices are: (a) *mean aggregate deviation* as determined from a series of plots measured on photos and on the ground, and (b) *the standard error of estimate from the same series of plots.*
2. Are there significant differences in the elapsed time needed to make the complete plot measurements of total height, crown-diameter, and crown-coverage? This entails using each instrument together with other common photo interpretation devices.
3. Do photo interpreters show an advantage in or develop a preference for using any one of the three instruments?

The Study

Basic data for this study were the records of five photo interpreters. Each man measured fifteen 1-acre plots each training day. The type of instrument used by each interpreter was changed daily so that each man had equal opportunity to gain skill with each instrument. The 15-plot series was selected to fit the daily training time allotted for these men, and also to allow for computation and testing of data.

Interpreters recorded their height measurements in terms of 0.001 inch, 0.00001 foot, or 0.01 mm., depending on the instrument they used. They also recorded crown-diameter in 0.001 inch and crown-coverage in per cent. After finishing measurements of each 15-plot group, the interpreter recorded total elapsed time for all measurements and interpretations.

A total of nearly 1,000 individual plot readings was made on nominal 1:20,000-scale panchromatic photos of the Black Hills and on nominal 1:12,000-scale photos of northern Idaho. Since each 1-acre plot measured had been previously measured on the ground, a true height was available for checking.

To reduce the possibility of bias, each interpreter was instructed to make independent readings, and to record stand height-readings as parallax difference in units typical of the instrument he used. Interpreters were given no opportunity to convert these readings to ground-height, and were completely unfamiliar with the ground conditions or the height measured in the field. They were not allowed to see the individual plot errors, but as a training measure were given their standard error of estimate and mean aggregate error for each 15-plot group at the end of each period.

Before starting these tests, each interpreter received a minimum of twenty 2-hour training periods in stand-height measurement. At the end of this period of training and familiarization, the standard control charts (3) indicated that the men could make reasonably consistent and satisfactory parallax readings with all three types of instruments.

All differences between photo and ground measurements of stand height were reduced to parallax difference in 0.001-inch units. Mean aggregate-error and standard-error of estimate were computed separately for each interpreter, instrument, and photo scale, by 15-plot groups.

Analysis of variance was used to test differences in these statistics and in the elapsed time of measurement recorded by the interpreters for each 15-plot group.

Results

Results of this study generally indicated no significant difference in the accuracy, variability, or time required to complete routine measurements on forest inventory plots when stand-height was measured with either parallax-wedge or height-finder, but use of the more complicated photo interpretometer significantly reduced both accuracy and speed. These differences are summarized in Table 1 which gives evaluation indices obtained from series of 15-plot groups:

Discussion of Results

The study generally confirmed earlier findings. It showed no significant difference in the accuracy of reading of stand-height made with the simple parallax-bar and the parallax-wedge.

Apparently forest photo interpreters can learn to use either the parallax-wedge or parallax-bar with equal speed and accuracy on small-scale (1:20,000) photos. On larger scale photos, accuracy was not significantly different, but measurements with the bar took significantly more time than was needed for measuring with the wedge. This time difference can be plausibly explained by the photo interpreter seeing more detail and

TABLE 1

Rating index	Parallax Wedge	Height Finder	Interpretometer
Data from 1:20,000-scale photos of Black Hills			
Mean aggregate difference (in 0.001 inch parallax)	1.54	1.53	[1]2.94
Standard error of estimate (in 0.001 inch parallax)	4.61	4.73	[1]6.12
Mean elapsed time (minutes)	66	60	[1]90
Data from 1:12,000-scale photos of northern Idaho			
Mean aggregate difference (in 0.001 inch parallax)	2.41	2.21	[1]4.09
Standard error of estimate (in 0.001 inch parallax)	8.62	8.21	9.12
Mean elapsed time (minutes)	63	[2]70	[2]71

[1] Significantly more than the other two readings.
[2] Significantly more than the other reading.

variation in the stand photographed at the larger scale. Also, he must traverse his instrument a greater distance. Under these circumstances, interpretations made with any floating dot device may take more time than those made with the wedge.

The data in the tabulation above also indicate that use of the more complicated photo interpretometer results in significantly slower and less accurate measurements than the use of either the wedge or bar. Several possible reasons for this can be summarized by saying that the interpretometer was not designed for this use. For example, the traversing distance is extremely short, and the interpreter frequently finds he must repeat his measurement using a second, wider-spaced dot. This becomes critical on large-scale photos of tall stands. The double micrometer scale and the line of usable dots complicate and consequently tend to slow down measurement. Finally, the transparent glass plates cover the plot area on the photos and prevent or complicate the use of other measuring devices needed in interpretation.

Both the parallax-bar and the photo interpretometer are fastened to and become an integral part of the lens stereoscope. The interpreter has two choices. He can, after completing his height measurement, set this scope aside and use a second one for the remainder of his interpretation. Or he can attempt to use the other measuring devices above or below the glass plates of his parallax device. Either system may be slower than use of the parallax-wedge, which is printed on film and is readily moved aside when the other measuring devices are used.

Although none of the many direct plotting instruments were available for use in this test, it seems probable that they would show some of the disadvantages of the interpretometer because they are even larger, and would tend to cover the photos and slow the use of other scales and devices. Use of the mirror scopes and larger parallax-bars would also, in our opinion, tend to slow interpretation without increasing accuracy.

When the higher cost of any of these instruments is considered, it seems apparent that the simplest and least complicated device that will measure with the required accuracy has significant advantages for the photo interpreter in forest inventory.

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