SLASH FUEL INVENTORIES FROM 70-MM LOW-LEVEL PHOTOGRAPHY

by

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"Slash fuel inventories from 70-mm low-level
photography" - by S.J. Muraro

Page 2. Caption Figure 1, lines 4 and 6:

for 5.45 read 4.35

for 4.06 read 3.66

ABSTRACT

Frequency and loading of fuel components calculated from photogrammetric and ground measurements were compared to assess the reliability of low-level 70-mm photography for slash fuel inventory. Although estimates of total fuel loading and number of components were less from photogrammetric data than from ground measurements, they were more consistent. The technique offers further advantages in speed and opportunity for re-inventory but is limited to fresh, unilayered fuel complexes.

RÉSUMÉ

Comparaison des valeurs de l'abondance et de la densité des matières combustibles obtenues par photogrammétrie et mensuration au sol pour déterminer la fiabilité de la photographie 70 mm à faible altitude comme technique d'évaluation des combustibles de déchet. **Supériorité qualitative des** données photogrammétriques, nonobstant l'infériorité quantitative des estimations ainsi obtenues par rapport aux mesures effectuées au sol. Autres avantages de cette technique au point de vue rapidité et opportunité de réévaluation. Inconvénient: limitation aux matières combustibles vertes et unisériées.

SLASH FUEL INVENTORIES FROM 70-MM LOW-LEVEL PHOTOGRAPHY

by

S. J. Muraro[1]

INTRODUCTION

Recent developments in the use of low-level 70-mm aerial photography (Lyons 1964, 1967) and the possibility of interfacing photogrammetric equipment with data processors enhance these techniques for fuel inventory. The main advantage of using low-level photography for fuel inventory is that measurements are obtained quickly and consistently, minimizing human error.

The purpose of this study was to determine if photogrammetric techniques are a reliable method of describing the slash-fuel complex resulting from recent clear-cut logging operations. Specifically, the objectives were

1. To compare ground and photographic measurements of:

   (a) number of fuel components by diameter class,
   (b) fuel loading by diameter class,
   (c) the diameters of specific fuel components,
   (d) the height above ground of specific fuel components.

2. To determine the minimum size of fuel components that can be recognized on the photographs and to determine alternative practical means of assessing smaller fuel components.

3. To evaluate, in general terms, errors in assessment resulting from fuel arrangements.

PROCEDURE

Field techniques

Twenty-four plots were located in slash resulting from clear-cutting stands of thrifty Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Each plot consisted of three semi-permanent baselines radiating from numbered plot centers at 120° intervals (Fig. 1). Fuel components intersecting each baseline were

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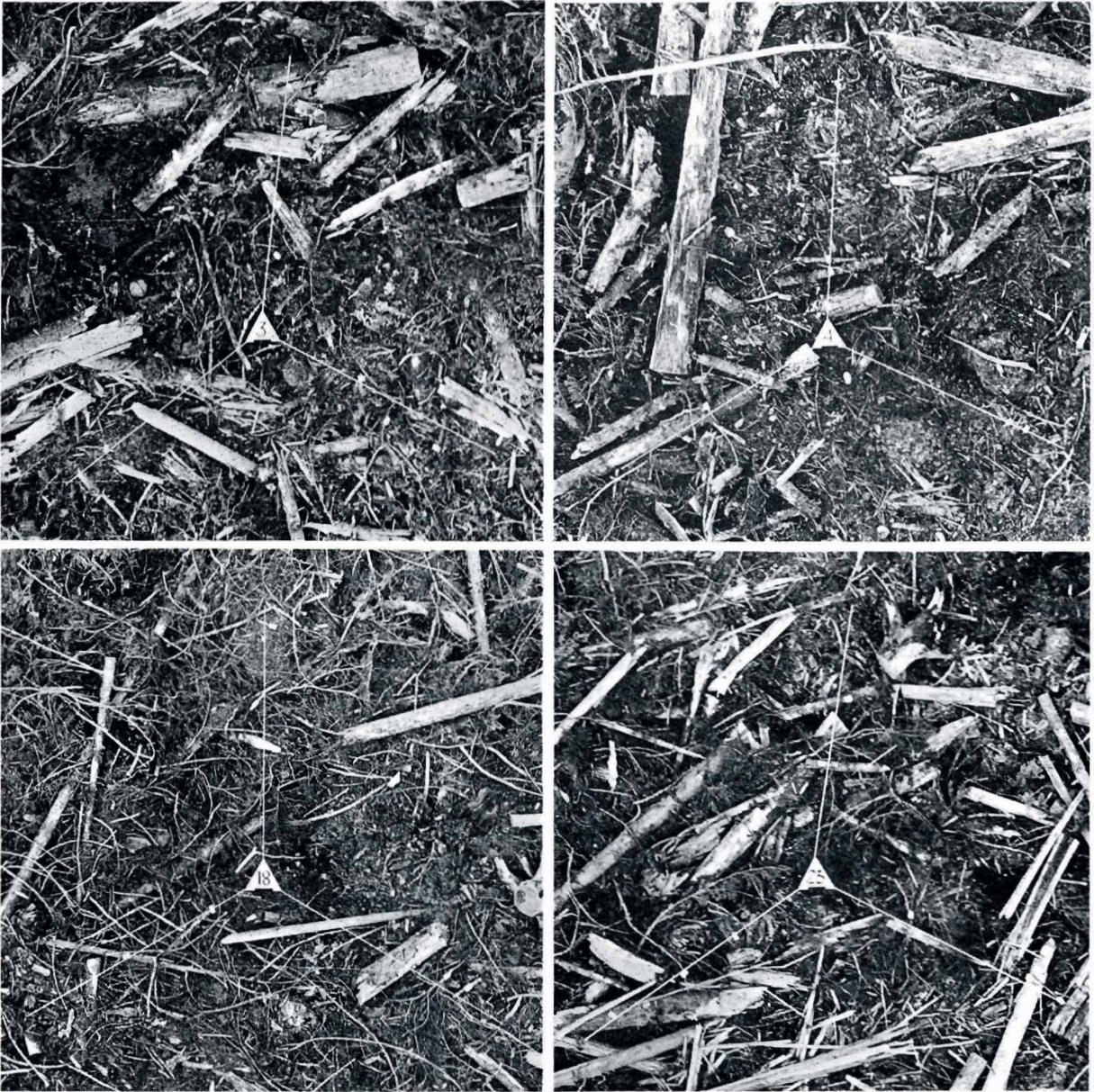
Figure 1.   Plot 3 - *Logging slash from cat-skidding operation.*
            Loading: Ground - 15.75 lb./ft^2; Photo - 8.09 lb./ft^2.

         Plot 4 - *Logging slash from cat-skidding operation.*
            Loading: Ground - ~~5.45~~ lb./ft^2; Photo - ~~4.06~~ lb./ft^2.
                         4.35   3.66

         Plot 18 - *Logging slash from high-lead skidding operation.*
            Loading: Ground - 5.45 lb./ft^2; Photo - 4.06 lb./ft^2.

         Plot 23 - *Logging slash from high-lead skidding operation.*
            Loading: Ground - 11.48 lb./ft^2; Photo - 9.39 lb./ft^2.

independently counted by three operators, according to the technique des-
cribed by Van Wagner (1965). Fuels larger than 1.0 inches were counted
along 10 ft of each baseline and those of lesser diameter along 2 ft of each
baseline. Three fuel components on each baseline were marked by 3 x 5-inch
white cards tacked to their upper surfaces. The diameter, to the nearest
0.1 inch, and the vertical distance from the ground to the upper surface of
each marked fuel component to the nearest 1 inch, were measured and recorded.

The plots were later photographed from heights of approximately
100, 250 and 400 ft by two simultaneously activated 70-mm cameras mounted on
a helicopter (Lyons 1967). Enlarged prints were made, and the ends of each
10-ft intersect line were verified on the ground and marked on the print.

Photogrammetric techniques

In the laboratory, measurements of the fuel complex were made from
diapositives to maximize resolution. Inspection showed that photographs
taken from 100 ft were most suitable for the intended measurements. Three
photogrammetric techniques were tested for measuring the general fuel
complex:

(a) direct measurement using a collimator lens,
(b) projection of diapositives,
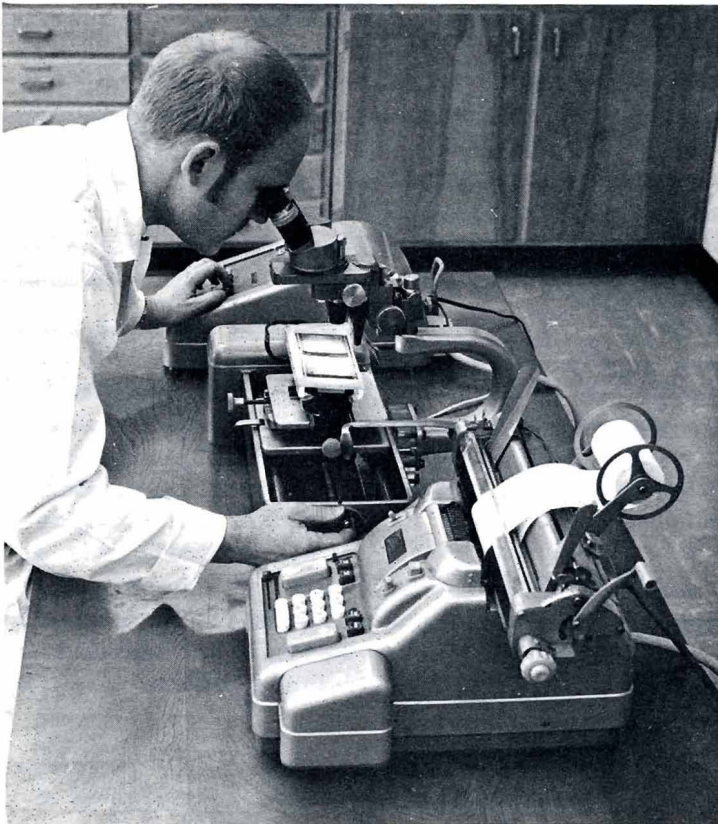(c) direct measurements using a modified Addo X model 353 tree ring
analyser (Fig. 2).

Figure 2. Addo X tree ring
analyser modified for photo-
grammetric measurements.

VERTICAL HAIR

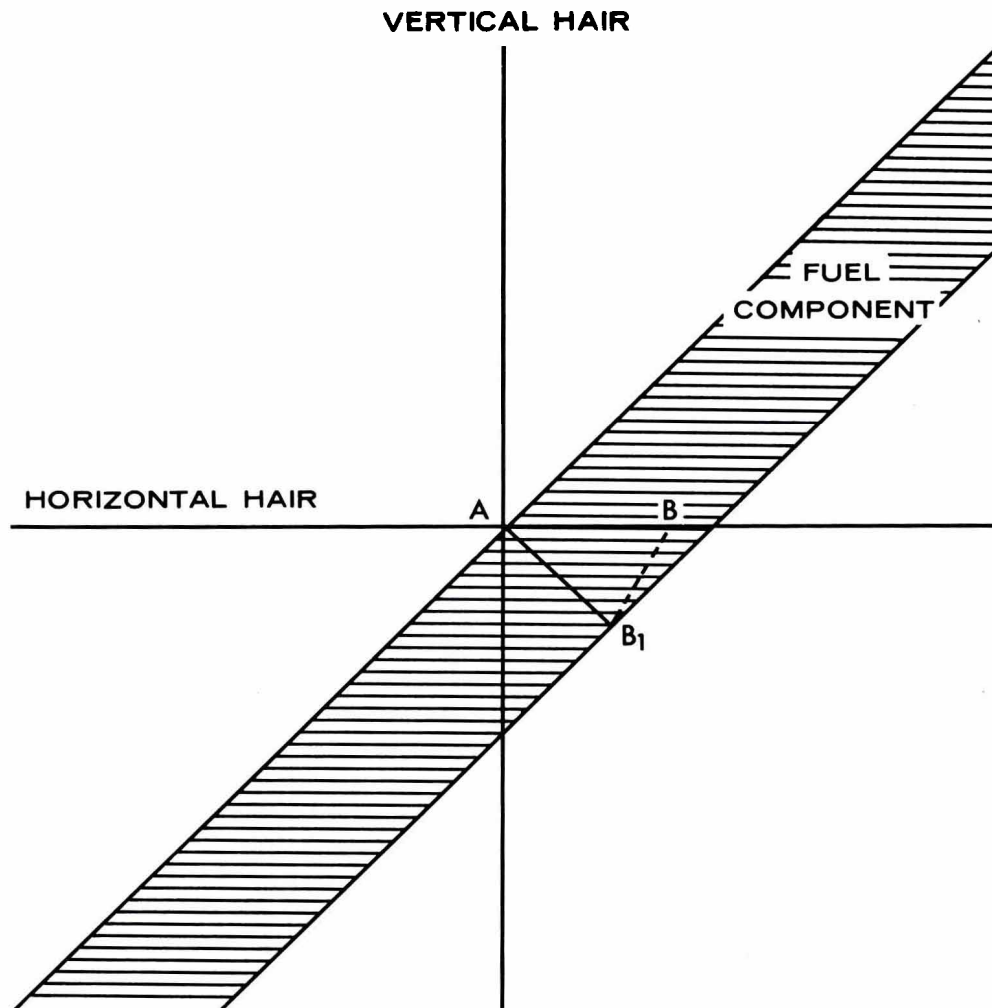HORIZONTAL HAIR

A B FUEL COMPONENT B₁

Figure 3. Schematic representation of measuring randomly oriented fuel components.

The modified Addo X was superior for measuring randomly oriented fuel components if the estimated length of line AB (Fig. 3) was measured to avoid the discontinuity resulting from alignment of the cross hair with line AB$_1$. Using this technique, three operators independently measured the diameter of each fuel component intersecting the same baselines used for the ground measurements.

The diameters of 216 marked fuel components were measured with the collimator lens; in addition, the diameters and heights of 90 components on 10 plots were measured with a Wilde A40 Plotter. Reliable measurements of fuel height could not be obtained with an Abrams height-finder.

ANALYSIS AND RESULTS

Fuel distribution and loading

The measurements of the three ground operators and the three Addo X operators were programmed for computer analysis to provide:

(a) number of fuel components in each diameter class by operator and method,

(b) fuel loading (lb./ft^2) in each diameter class by operator and method,

(c) a test of the difference in fuel loading calculated from ground and photographic measurements.

Table 1 shows the mean number, mean loading and standard deviations together with method and diameter class. Standard deviations of frequency from the Addo X measurements were less than for the ground measurements in all diameter classes except the 6- and 8-inch class. Except for the 2- and 20-inch diameter classes, the mean number of components observed on the photos was less than the number tallied by the ground operators. These results indicate that photographic measurements are more consistent than ground measurements; however, the possibility of components being missed is greater.

When fuel loading is considered, standard deviations for the three photo operators were less than for the ground measurements in all except the 6- and 8-inch diameter classes. None of the standard deviations for either number of pieces or loading in diameter classes greater than 1.0 inch were significantly different when observations made by ground and photo operators were compared.

Photographic measurements allow accurate calculations of fuel loading because actual diameters are recorded. The usual field procedure is to tally fuels by size classes and use class midpoint diameter in subsequent calculations of fuel loading. In Van Wagner's (1965) formula,

fuel loading (lb./ft^2) = $\dfrac{0.535 \ S(d^2)}{L}$ when S is specific gravity, L is

length of intersect in feet and d is diameter of the fuel component, differences between the assumed midpoint and true midpoint are squared. Deviations from true midpoints attain greatest significance in the small diameter classes where number of components and skewness are greatest. In Table 1, the effect of an erroneously assumed midpoint diameter is evident in the 2-inch diameter class where there were more fuel components recorded from the photographs (23.16 versus 18.73). However, the calculated fuel loading is 0.668 lb./ft^2 from the ground data and 0.498 lb./ ft^2 from the Addo X data. The error introduced by using midpoint diameters rather than actual diameters on the photographic data is shown in Figure 4.

TABLE 1. MEANS AND STANDARD DEVIATIONS OF FUEL LOADING AND NUMBER OF FUEL COMPONENTS BY SIZE CLASS, DETERMINED BY THREE GROUND OPERATORS AND THREE PHOTOGRAMMETRIC OPERATORS

Diameter class (inches)	No. of fuel components/plot				Fuel loading (lb./ft^2)			
	Mean of 3 ground tallies	S. D.	Mean of 3 photo tallies	S. D.	Mean of 3 ground tallies	S. D.	Mean of 3 photo tallies	S. D.
.1*	380.02	139.915			.028	.006		
.11–.50*	126.73	32.755	9.19	11.832	.103	.026	.011	.026
.51–1.0*	29.31	17.460	24.74	9.628	.132	.076	.127	.051
1.1–3.0	18.73	14.549	23.16	10.544	.668	.519	.498	.295
3.1–5.0	2.22	2.041	2.14	1.691	.313	.291	.285	.200
5.1–7.0	1.20	.833	1.18	1.130	.388	.262	.392	.367
7.1–9.0	.85	.850	.79	1.041	.483	.466	.440	.615
9.1–11.0	.57	.782	.51	.552	.545	.681	.364	.539
11.1–13.0	.35	.687	.19	.441	.463	.882	.237	.614
13.1–15.0	.35	.577	.29	.527	.606	1.009	.513	.926
15.1–17.0	.19	.577	.16	.500	.443	1.262	.385	1.129
17.1–19.0	.29	.471	.10	.288	.843	1.274	.362	.845
19.1–21.0	.08	.462	.10	.288	.300	1.205	.374	.984
21.1–23.0								
23.1–25.0								
25.0	.06	.236			.335	1.421		

*For these size classes ground tally is from 1/5 of the transect distance used on other size classes; therefore, to be comparable these values have been multiplied by 5.
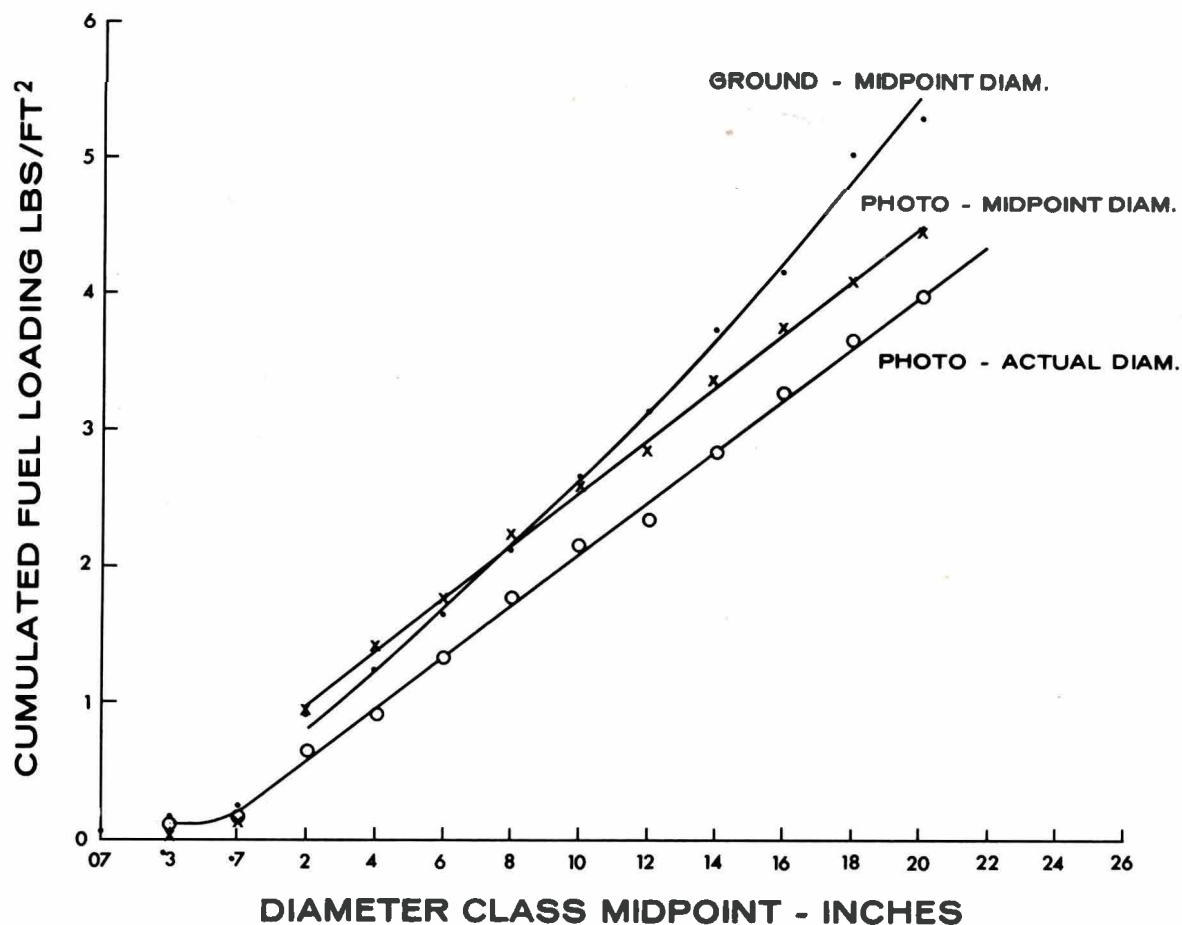
Figure 4. Cumulated fuel loading calculated from ground and photograph measurements using actual component diameters and class midpoint diameters.

Friedman's (Siegel 1956) two-way analysis of variance to test the difference in total fuel loading calculated from ground and photographic measurements showed:

  (a) no difference in fuel loading from the three ground operators at the 1% level of probability,
  (b) fuel loading from the three photographic operators was different at the 1% level,
  (c) fuel loading from the three ground operators and the three photographic operators was different at the 1% level,
  (d) no difference in fuel loading among operators at the 5% level, when the measurements of operator #6 were removed.

This test was conducted on fuel loadings calculated from class midpoint diameters from both the photographs and ground measurements. The results of this test, using actual diameters from the photographs, were the same, except (d) which remained different at the 1% level.

Diameter and height of specific fuels

Ground and photographic measurements of diameter and height of
the marked fuel components were compared to evaluate the accuracy of
measuring individual fuel components. To compare fuel diameters, 216 mea-
surements determined with the collimator lens and 90 measurements using
the Wilde A40 Plotter were stratified by the diameters of the same fuel
components measured on the ground and the 95% confidence limits calculated.
The means of the two photo methods and the 45° line of perfect agreement
with the ground measurements are shown in Figure 5.

Fuel diameters from both photogrammetric methods were larger than
those measured on the ground; measurements with the collimator lens varying
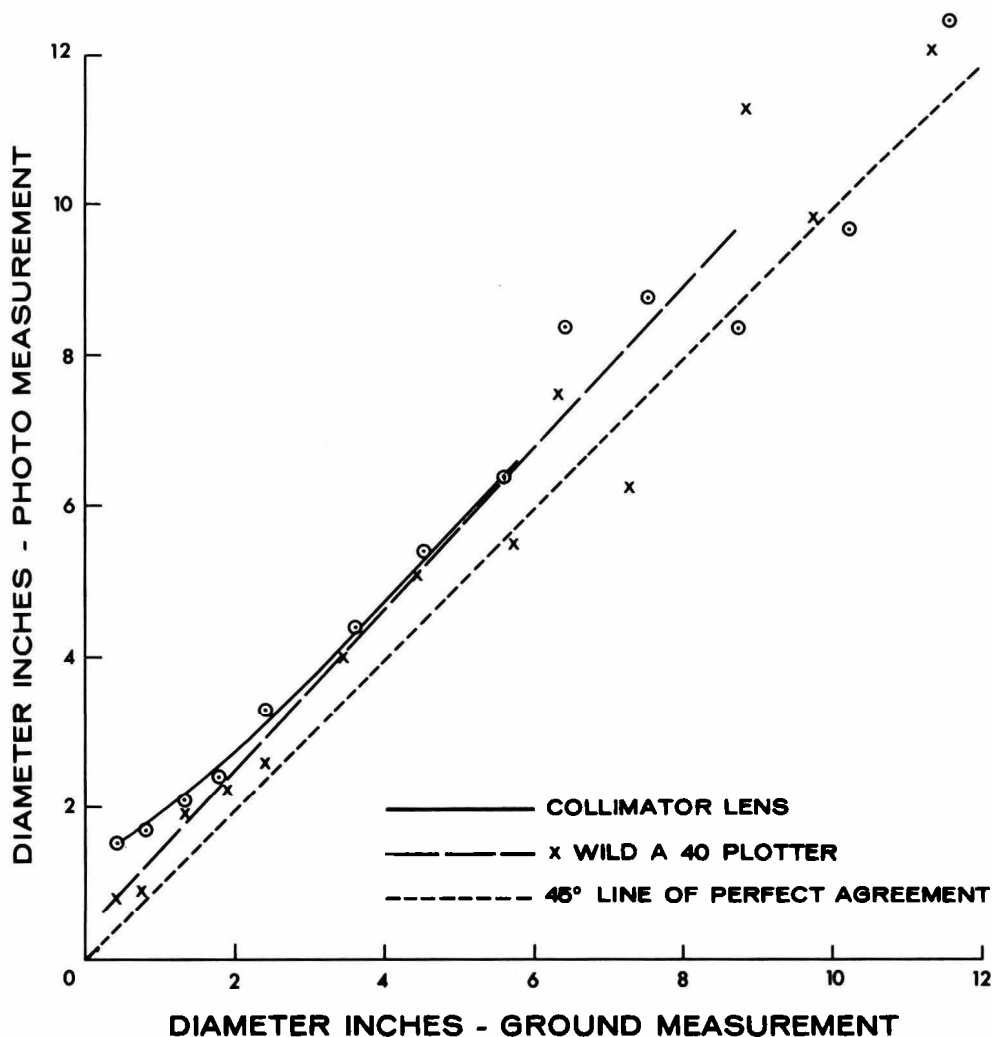inversely and the Wilde A40 Plotter measurements varying directly with

Figure 5. *Mean diameters of specific fuel components measured from the
photographs with a collimator lens and by the Wilde A40 Plotter
stratified by mean diameter classes measured on the ground.*

diameter. The line of agreement is within the 95% confidence limits of all the means measured by the Wilde A40 Plotter but is outside these limits for all the collimator determined means smaller than 8 inches.

Duncan's multiple range test verified these results, showing all ground measurements to be the same and all differing from the collimator lens' measurements. Students' "t" test showed measurements from Wilde A40 Plotter represented the same population as measurements recorded by the most experienced ground operator.

The comparison of fuel height measured by ground operator #1 and on the Wilde A40 Plotter showed a consistent bias of 5 inches in favor of the photographic measurement. Intuitively the reverse would be expected because of the false ground level presented by the surface vegetation. The bias which may be system or operator oriented could be corrected by calibration, an accepted practice in photogrammetry.

Limitations of fuel size

No fuel component in the less than 0.10-inch class was measured with the Addo X, although ground operators recorded an average of 380.02 pieces (Table 1). In the 0.11- to 0.50-inch diameter class, the ground operators recorded a mean of 126.73 components compared to 9.19 components from the photographs. The mean difference of five pieces between the two methods in the 0.5- to 1.0-inch class indicates that fuels smaller than 0.5-inch diameter cannot be identified on the photographs. To circumvent this problem, the number of fuel components in the <0.1, 0.11 to 0.50 and 0.51 to 1.00-inch classes was collated with fuel loading in each 2-inch diameter class to develop a prediction equation for the fine fuels. The results verified similar tests in other fuel complexes, showing a uniform lack of dependence of the number of fine fuel components on fuel loading in any one or all classes. However, the number of fuel components in the diameter class less than 1.0 inch was relatively consistent and could therefore be estimated from a limited ground survey.

The validity of this approach was substantiated by showing that an error of one standard deviation in an estimate of the number of fuel components in the two smallest diameter classes would be less than ±1% of total fuel loading. The significance of this error is greater if fuel characteristics of fineness or surface area are considered rather than loading.

Limitations of fuel arrangement

Arrangement of the fuel components influences agreement between ground and photo measurements. On plots where the fuel was concentrated in piles by dozers (Fig. 1, plot 3), the differences between all ground and all photographic measurements exceeded 10 lb./ft². Dozer-logged areas where the fuel was evenly distributed (Fig. 1, plot 4) resulted in ground- and photo-operator differences similar to those found in the evenly distributed high-lead slash (Fig. 1, plot 18). In high-lead slash, even

though two plots involved fuel loadings nearly equal to the heaviest loading encountered in dozer-logging, the tendency toward unilayered fuel complexes (Fig. 1, plot 23) resulted in the same order of differences between methods as encountered in the more normal loadings.

Fuel components are also obscured by shadows and invading herbaceous vegetation. The effect of shadows is reduced if photography is done on overcast days. Invading vegetation limits the use of photographic fuel inventory to areas logged within one growing season.

CONCLUSIONS

Within the limitations of slash-age and arrangement, fuel loading calculated from measurements on 70-mm photography are equally reliable as those obtained from conventional ground sampling. Photographic measurements of the fuel complex which were biased could be corrected by applying standard photogrammetric calibration techniques. Recent improvements in both photographic and photogrammetric equipment and the potential to improve interpretation through training and calibration offer a greater latitude for improved fuel inventories from photographs than from ground techniques, which leave little room for improvement.

In addition, the following advantages provided by the photographic technique outweigh the inconclusive accuracy for some measurements.

(1) Provision of a permanent record that can be checked at will to substantiate evidence of eccentric fire behavior or provide reasons for abnormal impact.

(2) Speed of sampling and the capability for interpretation in conditions unaffected by adverse working conditions.

This method should not be used to assess old slash where vegetation has invaded or in bunched or piled fuel complexes.

SUMMARY

Fuel inventories on 24 plots located in freshly-logged high-lead and cat-skidded slash areas were measured by ground operators using the intersect technique. Twenty-four of the plots were later photographed by two 70-mm cameras on a fore- and aft-oriented boom mounted on a helicopter. Fuel loading and distribution of fuel components by size classes obtained from the ground measurements and by various photogrammetric techniques were compared to determine if fuel inventories could be obtained by photographic techniques.

Results of the analyses showed:

(1) Fuel loadings obtained from photographic measurements were slightly less, but more consistent, than those obtained from ground measurements.

(2) When the results of the lowest photographic operator were omitted, there was no difference at the 5% probability level in fuel loadings calculated from class midpoint diameters.

(3) The diameters of marked fuel components measured with the Wilde A40 Plotter and collimator lens on photographs were larger than the diameter of the same fuel components measured on the ground. There was no difference in diameters measured by the Wilde A40 Plotter and those measured by the most experienced operator.

(4) The depth of the fuel complex could not be measured with an Abrams height-finder and a consistent 5-inch bias was obtained from measurements made on the Wilde A40 Plotter.

(5) Fuel components smaller than 0.5-inch diameter could not be measured on the photographs; however, limited sampling of these fuels will provide acceptable estimates of loading. Frequency of these fuel components was independent of larger fuels.

(6) The photographic technique described is not suitable for assessing piled fuel complexes or old slash obscured by vegetation.

In the author's opinion, descriptions of the slash-fuel complex on recent clear-cut areas from measurements on low-level photographs are more than adequate for all operational and most research purposes. The flexibility, consistency and opportunity for verification of inventory results are further reasons for recommending this technique where it is logistically compatible with particular requirements.

ACKNOWLEDGMENT

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