W. A. Befort
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, ID 83843
B. L. Kessler*
Idaho Department of Lands
Moscow, ID 83843
H. N. Anderson†
College of Forestry, Wildlife and Range Sciences
University of Idaho
Moscow, ID 83843

Stand Density Estimation on Panoramic Transparencies

When viewed at the same scale, estimates of stand densities made from panoramic photography were not significantly different from those made from black-and-white photography.

Introduction

Foresters frequently make estimates of canopy density—sometimes termed crown closure, canopy closure, crown density, or crown cover (cf. Society of American Foresters, 1971)—from aerial photographs. Such estimates have long played a part in photo measurement of stand volumes (Spurr, 1948; Avery, 1977). More recently, they have been put to use in schemes for rating forest stands as to probability of attack by insects (Heller *et al.*, 1977; 1980).

In the course of such a risk-rating project, the question arose whether estimates of density taken from high-altitude panoramic color infrared transparencies, newly available to us through the U.S. Forest Service's Nationwide Forestry Applications Program and NASA's Airborne Instrumentation Research Project, might properly be substituted for estimates taken from conventional 9-by-9-inch black-and-white prints. If we could use the recent panoramic photography in our possession, we would avoid the expense of purchasing conventional photos, and the difficulty of assembling and interpreting a patchwork of prints taken at various scales and dates. We decided to see whether there was a difference between density estimates made on the same plots with the two kinds of photography.

Abstract: *Paired estimates of forest canopy density were made on optical bar panoramic* CIR *transparencies and on conventional black-and-white prints to see if different results would be obtained. Except in the portions of the photographs beyond about 36° of scan angle, estimates made on panoramic photos under 4× stereo magnification were not significantly different from estimates made on conventional photos with a 3× mirror stereoscope.*

Methods

Our panoramic transparencies were duplicates of July 1979 exposures made from a NASA/Ames U-2 research aircraft with the Itek KA-80A Optical Bar Panoramic Camera on Kodak SO-131 High Definition Aerochrome Infrared film. The KA-80A scans a 120° panoramic swath perpendicular to the direction of flight, and creates a 50.3-in. by 4.6-in. image on the film. Like all panoramic imagery, KA-80A photography displays "panoramic distortion": the object scale decreases with lateral dis-

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* Now with College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843.

† Now with the Idaho Department of Water Resources, Boise, ID 83720.

Photogrammetric Engineering and Remote Sensing,
Vol. 47, No. 10, October 1981, pp. 1477-1481.

0099-1112/81/4710-1477 $02.25/0

placement from the nadir. For measurements made in the direction of flight, scale is inversely proportional to the cosine of scan angle; for cross-track measurements, scale changes with the square of the cosine.

The focal length of the KA-80A is 24 inches, and the usual flying altitude of the U-2 is about 60,000 feet above terrain. The nominal scale of the photography is, therefore, about 1:30,000 at the nadir, dropping to 1:60,000 (in-track) and 1:120,000 (cross-track) at the extreme 60° scan angle.

From the usual altitude, the full 120° scan of the KA-80A takes in a 40-mile swath of ground. For practical forestry purposes, the useful portion of the image is considered to be the central 70° or 80° of scan (Dillman *et al.*, 1980; Klein *et al.*, 1980) and missions are customarily planned with flight lines about 16 to 19 miles apart, so that sidelap occurs at about 35 to 40° of scan to one side. Thus, the outer 9 to 10 inches of film on each end of the KA-80A exposure are in sidelap and redundant. This fact, coupled with the general unwieldiness of a 50 in. by 5 in. strip of film, has led California foresters and others to prepare optical bar transparencies for field and office work by cutting them into five 10-inch segments, first protecting the transparencies with plastic laminating materials (Caylor *et al.*, 1978). We accepted this system of division.

The separated parts of a panoramic frame fall into three categories:

- Central section, five inches (12° of scan) to left and right of the middle of the photograph. This section has little panoramic distortion; nominal in-track scale varies from 1:30,000 to 1:30,700. Obliquity of view is no greater than in the central 2.6-in. circle of a conventional photograph taken with a 6-in. focal length camera. Given equivalent viewing scale, there is no apparent reason to expect that density estimates in this part of the frame should differ from those made on conventional prints.
- Midscan section, five to fifteen inches from center of frame. Scan angle starts at 12° and rises to 36°; in-track scale starts at 1:30,700 and drops to 1:37,100. Obliquity in this section rises above the maximum (30° or so) that would ordinarily be encountered in conventional 6-in. focal length photography, so masking of stand openings may begin to raise canopy density estimates. The reduction in scale should also tend to increase apparent density.
- Endscan section, the outer ten inches of the frame. In-track scale falls from 1:37,100 to 1:60,000 and obliquity rises from 36° to 60°, only 30° below horizontal. Masking and small scale may be expected to raise density estimates. However, under the usual flight specifications most of this section is in sidelap, beyond the effective area of the frame.

We chose an available set of August 1976 Forest Service panchromatic minus-blue 9- by 9-in. prints, taken with a 6-in. focal length Wild camera at a nominal scale of 1:24,000, for comparison purposes. In the stereo models of 12 pairs of these photos, depicting coniferous forest land in the Clearwater Mountains north of Potlatch, Idaho (about 2000 feet of local relief), we pinpricked the centers of 90 plots. We transferred these to the five corresponding panoramic frames, using a Bausch & Lomb Zoom Transfer Scope. Our aim was to have 30 plots in each of the three sections of the panoramic photography, each section having three plots in each of 10 canopy density classes from 5 to 95 percent. Our plot location procedure was slightly at fault, and we ended with 28 plots in Central sections, 29 in Midscan sections, and 27 in Endscan sections of the panoramic photos, for a total of 84. Plots were not placed where gross changes in cover (e.g., timber sales) had occurred between 1976 and 1979. Apart from these areas, there was no reason to expect that canopy densities would have changed appreciably during this period.

Since we did not plan to obtain "ground truth" on the density of these plots (there is no practical technique for ground measurement of canopy density in any case), our distribution of plots in density classes was bound to be somewhat erratic: the interpreter picking a plot center on the conventional photography might later find himself overruled as to its "true" density by a consensus of other interpreters.

Circular two-acre plot boundaries were drawn on the two sets of photos. Plot diameters were progressively reduced on the optical bar photography to compensate for in-track (1/cos scan°) scale change. Cross-track scale change, which would have produced elliptical plots at high scan angles, was ignored.

Five interpreters, all with college photointerpretation training and forestry photointerpretation experience, estimated plot densities and placed the plots in ten equal density classes with midpoints from 5 to 95 percent. The conventional prints were viewed with a Nikon mirror stereoscope at 3× magnification. The optical bar transparencies were viewed with a Bausch & Lomb Zoom 240 stereoscope over a Richards MIM-4 light table, and were interpreted twice, once at a high magnification chosen by the interpreter and once at a fixed four-power magnification. (These two interpretations were carried out separately.) Interpreters were provided with a comparative density scale for reference, and were instructed to take the effect of obliquity mentally into account, estimating the "actual," i.e., vertically viewed, density of panoramic plots as accurately as possible.

The Zoom 240 stereoscope was fitted with 0.43-power objective lenses and 10-power eyepieces, giving a magnification range from 3× to

13×. The high-magnification test was run in order to see what happened to density estimates when interpreters were allowed to take full advantage of the high resolution of the panoramic photos (about 25 line pairs/mm). The fixed 4× magnification trial was intended to approximate the conditions under which field foresters might expect to find themselves making density estimates on optical bar photography, using standard equipment such as the Abrams CB-1 2×/4× stereoscope (Caylor, 1978; Dillman *et al.*, 1981; Klein *et al.*, 1980; Befort *et al.*, 1980). The 4× magnification also brought the panoramic transparencies to roughly the same perceived scale as the conventional prints viewed under 3× magnification.

RESULTS AND DISCUSSION

Differences between conventional and optical bar panoramic (OBP) density estimates on the same plots were analyzed for significance. Paired t-tests applied to plots in the three different sections of photography yielded the results shown in Table 1.

In the Center section, density estimates from panoramic photography viewed under high magnification were slightly but significantly lower than those from conventional photography. Magnification, allowing better perception of holes in the canopy, may explain the difference. In the Midscan section, the same effect was evident, and the OBP/high magnification estimates were also significantly lower than OBP/4×. The OBP/4× estimates did not differ from conventional estimates in either of these sections. In the Endscan section, effects were reversed, and estimates from both panoramic methods were significantly higher than conventional; OBP/4× estimates exceeded OBP/high magnification estimates as well.

Inspection indicated that differences in density estimates probably varied to some degree with the levels of density being estimated, so we decided to break the figures down into density classes within sections. We took the mean of the five interpreters' estimates from conventional photography as establishing the "true" density of each plot, regardless of whether panoramic estimates agreed or not. Then we tested the differences of paired density interpretation means within each 10 percent class. Significant differences are given in Table 2.

These paired comparisons yielded relatively few significant differences, and no consistent pattern. Optical bar/high magnification estimates did not differ significantly from conventional estimates in any density class in the Central section. In the Midscan section, OBP/high gave significantly larger estimates than conventional in the 5 percent and 35 percent density classes, and lower estimates in the 75 percent and 95 percent classes. OBP/4× estimates in the Central section were significantly larger than conventional estimates only in the 85 percent density class; in the Midscan section, OBP/4× gave higher estimates in the 5 per-

TABLE 1. DIFFERENCES BETWEEN PAIRED DENSITY ESTIMATES, BY SECTION

Paired Comparison	No. Pairs	Mean Difference	Std. Error of Difference
	Central Section		
Conventional minus OBP/high	140	2.64**	1.00
Conventional minus OBP/4×	140	1.29	1.01
OBP/high minus OBP/4×	140	−1.36	0.69
	Midscan Section		
Conventional minus OBP/high	145	2.41*	1.11
Conventional minus OBP/4×	145	−0.83	1.03
OBP/high minus OBP/4×	145	−3.24**	0.83
	Endscan Section		
Conventional minus OBP/high	135	−4.22**	1.44
Conventional minus OBP/4×	135	−7.33**	1.45
OBP/high minus OBP/4×	135	−3.11**	1.01

* denotes statistical significance at 0.05 level.
** denotes statistical significance at 0.01 level.

TABLE 2. SIGNIFICANT PAIRED MEAN DENSITY ESTIMATE DIFFERENCES BY SECTION AND DENSITY CLASS

Class	Center	Midscan		Endscan	
5%		C-OB/H C-OB/4	−2.8** −2.0*	C-OB/H	−4.0**
15%				C-OB/H C-OB/4	−5.3* −6.0**
25%		C-OB/4 OB/H-OB/4	−7.5* −4.5*	C-OB/H C-OB/4 OB/H-OB/4	−5.3* −11.3** −6.0**
35%		C-OB/H C-OB/4	−16.0* −14.0*	C-OB/H C-OB/4	−18.0* −20.5*
55%				C-OB/4	−10.7*
65%		OB/H-OB/4	−6.7*		
75%		C-OB/H OB/H-OB/4	13.5** −9.0**		
85%	C-OB/4−8.0*			C-OB/H	11.0**
95%		C-OB/H	8.0*		

* denotes significance at .05 level.
** denotes significance at .01 level.
C = conventional; OB/H = optical bar/high magnification; OB/4 = optical bar/4X

cent, 25 percent, and 35 percent classes and no significantly lower estimates. OBP/high differed from OBP/4× in the 25 percent, 65 percent, and 75 percent classes of the Midscan section, OBP/4× giving higher figures.

In the Endscan section, panoramic estimates showed a more pronounced upward bias. OBP/high estimates significantly exceeded conventional estimates in the 5 percent, 15 percent, 25 percent, and 35 percent classes, and were lower only in the 85 percent class. OBP/4× estimates were significantly higher than conventional in the 15 percent, 25 percent, 35 percent, and 55 percent classes. The two panoramic magnifications gave significantly different results only in the 25 percent class, where OBP/4× estimates were higher.

We also desired to check the consistency with which the three estimation methods assigned plots to density classes. Here we could no longer accept the mean of conventional estimates as the "true" density of a given plot, so we calculated means of plot estimates separately for each estimation method, and assigned plots to density classes on the basis of these means. This gave us three somewhat different distributions of plots among density classes—one for conventional photography, one for optical bar/high magnification, and one for optical bar/4× magnification—in each of the three sections of photography. We calculated variances of the interpreter estimates within each section and density class, and tested them by the F-statistic according to their degrees of freedom. Results appear in Table 3. It will be seen that significant differences were comparatively few; also, that of 11 significant differences between variances of conventional and panoramic estimates, the conventional variance was the smaller in only four cases.

The differences between plot density estimates with the three photo/viewer combinations were subjected to analysis of variance to discover the factors influencing them. Independent variables were stand density (again derived by averaging conventional estimates of a given plot), its square, the section of panoramic photography, interpreter, and three two-way interaction terms.

Section of photography and a density class-section interaction term were the only independent variables identified as significantly influencing the differences between conventional and optical bar/high magnification estimates. A Duncan's multiple-range test distinguished Endscan differences from those of the other two sections.

Section of photography was again highly significant in analysis of differences between conventional and OBP/4× estimates, and Endscan differences were again distinguishable from the others. Other significant variables were the square of density class and the interactions of density class-section and density class-interpreter.

Analysis of differences between OBP/high mag-

TABLE 3. SIGNIFICANTLY DIFFERING VARIANCES OF DENSITY ESTIMATES, BY DENSITY CLASS AND SECTION

Class	Conventional		OBP/High		OBP/4X	
Central Section						
5%	$n = 15$,	$s^2 = 17.14$	$n = 20$,	$s^2 = 4.84$[aa]	$n = 25$,	$s^2 = 13.99$[bb]
45%	$n = 15$,	$s^2 = 135.26$	$n = 5$,	$s^2 = 19.98$[a]	$n = 5$,	$s^2 = 79.92$
55%	$n = 15$,	$s^2 = 335.26$	$n = 25$,	$s^2 = 190.99$	$n = 20$,	$s^2 = 104.24$[aa]
Midscan Section						
5%	$n = 25$,	$s^2 = 7.67$	$n = 15$,	$s^2 = 12.39$	$n = 25$,	$s^2 = 16.81$[a]
55%	$n = 15$,	$s^2 = 135.26$	$n = 25$,	$s^2 = 58.37$[a]	$n = 10$,	$s^2 = 84.46$
65%	$n = 15$,	$s^2 = 88.55$	$n = 15$,	$s^2 = 326.52$[aa]	$n = 20$,	$s^2 = 55.20$[bb]
Endscan Section						
25%	$n = 15$,	$s^2 = 42.90$	$n = 20$,	$s^2 = 122.10$[a]	$n = 20$,	$s^2 = 99.80$[a]
45%	$n = 10$,	$s^2 = 239.94$	$n = 5$,	$s^2 = 19.98$[aa]	$n = 15$,	$s^2 = 97.61$[ab]
55%	$n = 15$,	$s^2 = 117.07$	$n = 10$,	$s^2 = 32.26$[a]	$n = 10$,	$s^2 = 160.02$[bb]

[a] denotes significant difference (0.05 level) from conventional variance.

[b] denotes significant difference (0.05 level) from OBP/high variance. Double superscripts indicate 0.01 level significance.

nification and OBP/4× estimates showed a significant density class effect: as "true" density increases, so does the tendency of OBP/4× to yield higher estimates than OBP/high magnification. No other significant effect was shown. All these effects might well be explored further.

CONCLUSIONS

On the basis of our comparisons, we feel safe in concluding that

- If interpretation is confined to the central 70 to 75° (the central 30 inches) of the panoramic frame, as it ordinarily can be, canopy density estimates made from optical bar panoramic transparancies under four-power stereo magnification will not be significantly different from, or more variable than, estimates made from conventional resource photography with conventional stereoscopes; and
- Estimates from portions of the panoramic photo beyond 36° of scan will be biased upward from, but no more variable than, estimates made from conventional resource photography with conventional stereoscopes.

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(Received 22 August 1980; revised and accepted 29 March 1981)