Bijan Payandeh†
Robert B. Pope
David P. Paine

# Bias from Photo Intensity*

## A serious bias in forest area estimation using dot sampling occurs in the presence of uneven photo intensity.

Abstract: *Uniformity of photo intensity of forest and nonforest land-condition classes was investigated on six photo projects (counties) in western Oregon and Washington. No significant relationship was found between photo intensity and ground elevation. However, photo intensity of nonforested areas averaged 4.1 percent greater than that of forested areas. This difference was statistically significant. Thus, photo dot sampling for area estimation directly from aerial photographs could result in seriously biased estimates of forest area and volume. Unfortunately, procedures that might eliminate this source of bias are expensive.*

### Introduction

In extensive forest surveys and inventories in the United States and elsewhere, areas of various land-condition classes are often estimated directly from a sample of dots or plots on aerial photographs. These plots are commonly positioned systematically over the effective area of the photos. Each sampling unit is first classified as forest or nonforest; then more detailed forest type breakdowns are made.[2, 3, 4] The unbiased nature of such area estimates is especially important for total timber volume estimates.[3, 9]

This method is unbiased if applied to truly vertical aerial photographs taken over level terrain where the photos have uniform end and side lap and if the flying height over the datum plane is kept constant. However, in actual practice, few, if any, of these specifications are met. Therefore, bias in area estimation may result from excessive tip, tilt, scale variation within photographs and scale variation between photographs, or from a combination of two or more of these sources. To minimize or eliminate the possible bias introduced by some of these sources, various techniques and/or instruments have been developed. Conditions under which the possible bias could be assumed negligible have also been pointed out.[1, 5, 6, 7, 8, 10, 14]

### Uneven Photo Intensity‡

Uneven photo intensity represents another source of bias which has scarcely been recognized in the literature. Wilson[14] stated the need for uniform photo spacing but did not investigate the magnitude of possible bias from this source. Moessner[8] tested one source of unequal photo spacing when he examined photo intensity along the flight lines. He concluded that spacing was fairly uniform in his study. However, uniform spacing of flight lines is as important as spacing uniformity along flight lines, and perhaps more difficult to attain.

If uneven photo intensity occurs with a random pattern within a photo project, the possible bias introduced from this source would be equivalent to a random error, and would not be serious. However, if it is associated in some manner with the land-condition classes being sampled, the bias introduced could be important. Bias would result

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† The authors are, respectively, Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault St. Marie, Ontario; Project Leader Survey Techniques, Pacific N.W. Forest & Range Exp. Station, Portland, Oregon; and Assoc. Prof., School of Forestry, Oregon State Univ., Corvallis, Oregon.

‡ Photo intensity is defined here as the number of photos taken per unit of ground surface in a given photo project.

if different photo specifications were employed in photographing forested and nonforested lands. Bias might also arise if photographic specifications and land classes varied for different ground elevations. For example, different side- and end-lap specifications might be used over mountainous terrain than over level ground. In any event, wherever photo intensity is greater over a particular land-condition class, direct photo plot sampling for area estimation leads to an overestimate of the area of that land class.

Unfortunately, all known methods of eliminating such a possible bias are expensive. For example, one such technique involves selecting plot locations on an accurate topographic map of the area and then transferring them to the photos by means of radial line or stereoscopic plotter. Another possibility is to test each photo project for the magnitude of the bias and, if it is negligible, ignore the bias. If such tests indicate significant bias, one of the following alternatives should be chosen:

- Discard the use of photo plots for area estimation,
- Adopt some other unbiased (but expensive) procedure,
- Develop cheaper methods to eliminate the bias, or
- Use current methods and accept the risk of bias.

Whether or not the magnitude of such bias is large enough to be of practical consequence was one of the major objectives of this study.

## Materials and Methods

The basic materials used in this study consisted of USDA-ASCS photo index mosaics and USGS 15-minute quadrangle contour maps, covering six counties of western Oregon and Washington. Photo coverage of each county constituted a separate photo project. Counties were selected on the basis of (1) the availability of maps and photo mosaics of approximately the same scale, (2) the existence of both forest and nonforest land classes within each county and (3) topographic features. Only those counties with considerable elevational variation were considered because it was hypothesized that elevational variation might be the major reason for uneven photo intensity.

A standard township, i.e., a square area exactly six miles on a side, was chosen as the basic sampling unit. Because some of the original townships varied in size and shape, a series of standard townships was laid out on topographic quadrangle sheets. The boundaries of all standard townships within each photo project were then carefully transferred to photo index mosaics.

Through careful inspection of the photo index mosaics each township was classified as predominantly forest or nonforest land. As photo plot grids established on aerial photos are commonly restricted to the theoretical effective area (i.e., the net area, assuming 60 percent end lap and 30 percent side lap), the photo count was based on the number of effective areas, including fractional ones, that fell within a township boundary. Thus, the count of photos per township was proportional to the number of photo plots that would be expected to fall within that township. The mean elevation of each township was obtained by averaging the elevation of the 36 section centers within that township as read directly from the contour map. Mean township elevation ranged from 200 to 3,000 feet.

## Analysis and Results

To establish the relationship between variation in photo intensity and variation in ground elevation, stepwise multiple regression analysis was employed using a poly-

Table 1. Average Photo Intensity by Land-condition Class and Photo Project

| *Photo project (county)* | *Number in sample* | | | *Photo intensity per township* | | | *Difference as percentage of forest* |
|---|---|---|---|---|---|---|---|
| | *Forest* | *Nonforest* | *Total* | *Forest* | *Nonforest* | *Difference* | |
| Benton | 12 | 5 | 17 | 17.10 | 18.08 | +0.98 | +5.7 |
| Clark | 5 | 12 | 17 | 17.68 | 17.82 | +0.14 | +0.8 |
| Douglas | 16 | 6 | 22 | 16.53 | 16.75 | +0.22 | +1.3 |
| Jackson | 11 | 9 | 20 | 16.47 | 17.22 | +0.75 | +4.6 |
| Lane | 19 | 16 | 35 | 16.56 | 17.42 | +0.86 | +5.2 |
| Lewis | 20 | 11 | 31 | 18.42 | 19.41 | +0.99 | +5.4 |
| Total or weighted mean | 83 | 59 | 142 | 17.13 | 17.83 | +0.70 | +4.1 |

nomial model. Various regression analyses were made on the data for forest and nonforest land, and for a combination of the two, within each photo project (county). Similar analyses were made on the combined data of all six counties. In every instance the trend was slightly negative, i.e., photo intensity decreased as elevation increased, but slopes were nonsignificant. Thus, no significant relationship was found between variation in photo intensity and changes in ground elevation.

Average photo intensity for forest and nonforest land classes within each county is given in Table 1. As noted, photo intensity for nonforested areas was greater than that for forested areas in every case. Percentage differences ranged from 0.8 to 5.7 with an overall average of 4.1 percent (Table 1, Column 8). Analysis of variance with disproportionate subclass numbers[12, 13] was employed to test the statistical significance of these differences. Results of this analysis (Table 2) indicate that (1) photo intensity of nonforest land was significantly greater than that of forest land and (2) there was no significant interaction between land class and photo projects.

## Discussion

The results of this study revealed no significant relationship between photo intensity and ground elevation for the six counties studied. However, they did indicate that photo intensity for nonforest land was significantly greater than that for forest land. This would lead to a serious bias in area estimation if the usual method of dot sampling directly from photographs were employed. Such bias would occur wherever photo intensity was related in some manner to land-condition classes.

The fact that photo intensity of nonforest land was, on the average, 4.1 percent greater than that of forest land is of practical importance. If a forest survey is designed for a sampling error of ± 5 percent for volume/acre estimates, this sort of difference in photo intensity could cause an intolerable bias in the estimates of forest area and volume.

A possible reason for the difference in photo intensity lies in the ASCS aerial photography specifications. These require each photo to be centered on a block of four sections with successive camera stations 1 mile apart. At a photo scale of 1:20,000, this produces an end lap of 65 percent. This specification is easily enforced in urban and agricultural areas where section lines are readily visible. However, in forested areas where section lines are not visible, the specification is not enforced, and minimum acceptable end lap is 55 to 60 percent. This, of course, will tend to produce fewer photos per unit for forest land than for nonforest land. A similar possibility is that contractors are more careful to insure sufficient end and side lap in photographing cities and agricultural areas (nonforested) because they have a greater market for photos taken over such areas. These suggestions contradict the original assumption that the distance between flight lines and the distance between photos within flight lines would be shortened over mountainous terrain (mostly forest land) to insure complete photo coverage. The authors would appreciate comments from aerial photo contractors.

TABLE 2. ANALYSIS OF VARIANCE FOR PHOTO INTENSITY

| Source of variation | DF | SS | MS | F |
|---|---|---|---|---|
| Land class (forest-nonforest) | 1 | 16.69 | 16.69 | 26.00* |
| Photo project (county) | 5 | 88.81 | | |
| Interaction (error) | 5 | 3.21 | 0.64 | 1.14 |
| Within cells | 130 | 73.17 | 0.56 | |
| Total | 141 | 181.88 | | |

* Significant at the 1% level.

## References

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14. WILSON, R. C. 1949. The relief displacement factor in forest area estimates by dot templets on aerial photographs. *Photogramm. Eng.* 15:225–236.

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*ASP offers two conferences in October,*

*one at Disney World (see page 500) and*

*the other at Sioux Falls (see page 532).*

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## Meetings Schedule

ANNUAL CONVENTIONS

March 11–16, 1973* Washington Hilton, Washington, D.C.

March 1974* Chase-Park Plaza, St. Louis, Mo.

March 7–12, 1975* Washington Hilton, Washington, D.C.

FALL TECHNICAL MEETINGS

1973* Oct. 2–5, Disney World, Orlando, Florida; Jon S. Beazley, Florida Dept. of Transportation, H. Burns Bldg., Tallahassee, Florida 32304.

Sept. 8–13, 1974,† Washington Hilton, Washington, D.C.

1975,* (open), Phoenix, Arizona.

Sept. 28–Oct. 1, 1976,* Olympic Hotel, Seattle, Wash.; C. E. Buckner, 803 Seattle Municipal Bldg., Seattle, Wash. 98104.

Oct. 18–21, 1977, Little Rock, Arkansas.

SEMINARS AND SYMPOSIUMS

July 1973, Univ. of Maine, Orono, Maine. Fourth Biennial Workshop–Color Aerial Photography in the Plant Sciences.

October 1973, Sioux Falls, S. Dak. Management & Utilization of Remote Sensing Data. Convention Center and USGS EROS Data Center. Cosponsored by AIAA, IEEE and AGI. Dr. Harold T. Rib, 10129 Glenmere Road, Fairfax, Va. 22030.

INTERNATIONAL MEETINGS

July 1973, Mexico City, Mexico. Joint Technical Meeting with the Mexican Society of Photogrammetry.

Sept. 9–16, 1974, Washington Hilton, Washington, D.C., *14th Congress of the International Federation of Surveyors,* (FIG); Jeter P. Battley, Jr., P.O. Box 14262, Washington, D.C. 20044.

* Jointly with the American Congress of Surveying and mapping.

† To be held as part of the international Congress of FIG.