Forest Sci., Vol. 32, No. 4, 1986, pp. 1085–1091

Evaluating Forest Vegetative Cover with Computerized Analysis of Fisheye Photographs

S. S. Chan, R. W. McCreight, J. D. Walstad, and T. A. Spies

ABSTRACT. A versatile, computerized system for expediting analysis of fisheye photos of forest and shrub canopy conditions was developed and refined. The materials necessary for taking and analyzing fisheye photos are readily available and the methods easily learned. Although the equipment required (camera, fisheye lens, microcomputer, and related accessories) has a relatively high fixed cost, the efficiency and accuracy gained may justify implementing the system, particularly if large numbers of photos must be processed. Computerized fisheye photographic analysis is a practical tool for assessing and documenting forest vegetative cover and its implications for the radiation environment of understory plants. FOREST SCI. 32:1085–1091.

ADDITIONAL KEY WORDS. Hemispherical photography, forest vegetation management, probability of diffuse radiation, overstory-understory relationships.

FOREST SCIENTISTS and managers need a reliable means of evaluating canopy conditions (e.g., plant cover, encroachment, light impediment). For example, forest vegetation management involves manipulating overtopping and encroaching vegetation to enhance the environment of desirable tree seedlings. This requires accurate assessments of plant cover

---

The authors are, respectively, graduate research assistant, research assistant, professor, College of Forestry, Oregon State University, Corvallis, OR 97331, and research forester, USDA Forest Service, PNW Forestry Sciences Laboratory, Corvallis, OR 97331. We thank Dr. Peyton Owston for his advice and the use of his facilities and Mark Klopsch for his valuable assistance in developing the computer programs. We are also indebted to Dr. Gaylon Campbell and Dr. Glenn Klock for their work in adapting the fisheye analysis procedures to microcomputers. Support for this project was provided by the CRAFTS cooperative research program in forest vegetation management at the Forest Research Laboratory, Oregon State University. Mention of brand names or commercial products does not imply endorsement by the authors or Oregon State University. This is Paper 1974, Forest Research Laboratory. Manuscript received March 25, 1985.

and radiation conditions that have a strong biological bearing on plant survival, growth, and succession. Accurate characterizations of forest canopies are also valuable in evaluating overstory conditions for purposes of stand and wildlife management.

Historically, quantitative analysis of canopy conditions has been difficult in complex forest environments. The ocular estimate methods (subjective visual assessments, spherical densitometers) of evaluating canopy conditions are simplest and most common. However, ocular estimates are often inaccurate. Other methods such as the point-intercept method (Johansson 1985) may be more accurate, but require time-consuming sampling and provide only limited information about canopy conditions. A relatively accurate method requiring less time in the field is the recording and analysis of fisheye photographs to provide a record and variety of information on canopy cover and radiation conditions (Brown 1962; Anderson 1964, 1971; Jones and Campbell 1979; Lakso 1980; Miller 1981; Olsson et al. 1982).

A fisheye photograph is a projection of a hemisphere onto a plane. The problems with this technique have been the difficulty, high initial cost, and time required to analyze the complex photographs. Jones and Campbell (1979), Miller (1981), and Olsson et al. (1982) solved these problems by developing prototype computerized fisheye analysis systems. In the early 1980s we modified and enhanced Jones and Campbell's and Miller's computerized procedure. This paper describes our automated technique for analyzing fisheye photographs.

PHOTOGRAPHIC EQUIPMENT AND FIELD TECHNIQUES

We took fisheye photographs on Kodalith High Contrast Ortho Film #6556 Type 3 and Kodak Plus-X Negative Film (two standard film types that have found wide use in fisheye photography) with a 7.5 mm Canon equidistance fisheye lens mounted on a Canon AE-I Program camera body. The photographs were taken under a range of field conditions including steep terrain, heavy logging slash, and dense brush. The camera was mounted on a sturdy tripod and leveled with a bubble level to ensure that the film plane was horizontal. True north was always oriented toward the center top edge of the photograph to facilitate subsequent sun path and radiation analyses. Relatively slow shutter speeds and high f-stops were used to maximize depth of field.

The height of the camera above the ground surface depends on objectives. For example, in characterizing brush canopies and their effects on the understory radiation environment, fisheye photographs should be taken at the height of the tree seedlings. Positioning the camera, recording site data, and exposing the film at each point takes about 3 min under these conditions.

High-contrast photos for both films can be achieved by adjusting the shutter speed and f-stop to properly expose the vegetation and slightly overexpose the sky. It is also important that pictures be taken when radiation is mostly diffuse—during early morning or late afternoon and evening when the sun is at a relatively low elevation angle or when the sky is overcast. These conditions illuminate the canopy uniformly and minimize sun flares (overexposed areas on the negative) or shadows (false indications of cover due to shading) caused by direct sunlight, both of which make analyzing photos difficult and inaccurate. Figure 1 shows typical fisheye photos taken at approximately the same point through an overtopping shrub canopy during summer and winter.

The high contrast film can be exposed at a speed of either ASA 8 or ASA 25. The faster ASA speed was useful on breezy days when foliage was not stationary. The film was developed in Kodalith developer when an ASA speed of 8 was used and in Kodak D-11 developer when a speed of ASA 25 was used. The Kodak Plus-X film was exposed at an ASA setting of 125 and developed in Kodak D-76 developer (Pittaro 1979). Processed negative film was then mounted as slides to facilitate analysis. Cost of materials and labor was about 10¢ per slide for film processing and mounting.

AUTOMATING THE ANALYSIS

We developed a computerized system in which the negative of the fisheye image is projected with a slide projector onto a flat surface, and the light is then electronically sensed, converted to a digital signal, stored, analyzed, and printed (Figure 2). Analyzing each slide in this fashion takes less than 2.5 min for high contrast photographs and 5 min for lower contrast photographs where gray density thresholds need to be set. Our equipment included

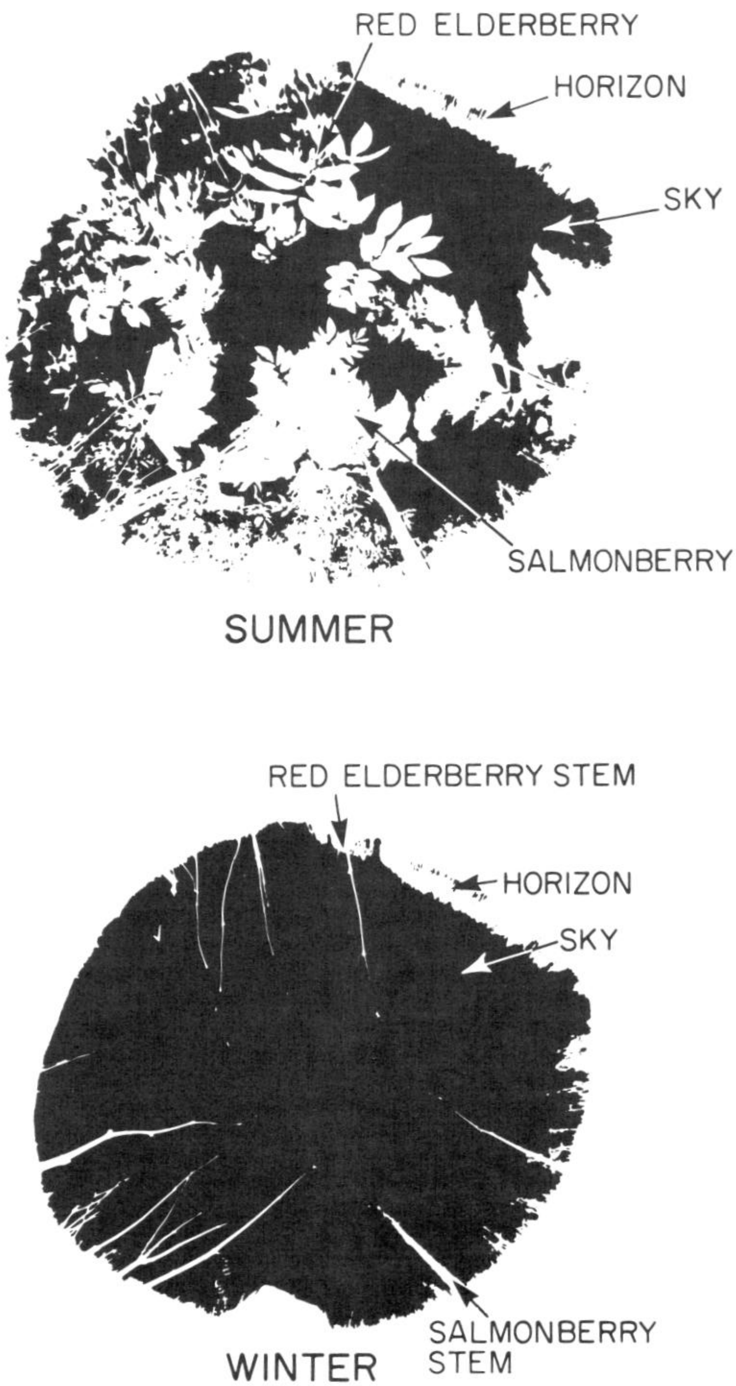

FIGURE 1. Fisheye photographs (negatives) taken from approximately the same point beneath a canopy of red elderberry (*Sambucus callicarpa* L. var. *arborescens*) and salmonberry (*Rubus spectabilis* Pursh.) shrubs during summer (38% probability of diffuse radiation penetration) and after leaf abscission in winter (86% probability of diffuse radiation penetration).

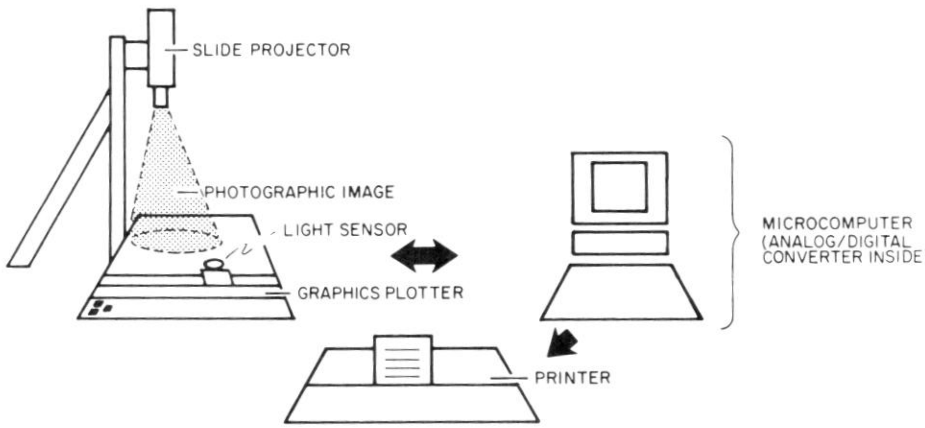

FIGURE 2. Schematic of the automated fisheye photographic analysis system.

an Amdek D-X-Y graphics plotter connected to a Zenith Z-100 microcomputer, a light sensor (silicon photovoltaic cell), an analog-to-digital (A/D) converter board (Tecmar® S-100 High Speed 12-Bit converter with a relative accuracy of ±0.025% full scale) that plugs into the microcomputer, a printer, and a slide projector.

In our arrangement, the slide projector was pointed downward from a stand so that an image with a diameter of 20 cm was projected onto the plotter. A grid system of concentric circles at 5° increments in elevation angle was programmed into the microcomputer which, in turn, controlled the plotter arm containing the light sensor. The light sensor, set to sample the zone between each consecutive 5° increment, was programmed to follow the circular grid path through each zone from the image's horizon (0°, i.e., the perimeter of the image) to its zenith (90°, i.e., the center of the image). The light sensor was 0.2 cm in radius and was placed inside a shallow opaque tube on the plotter's pen holder to prevent confounding of the analysis by extraneous light sources coming from the sides. The light intensity from the projected image was recorded by the sensor and converted from analog (voltage) to digital signals by the A/D board inside the microcomputer. Those digital signals were then stored in the microcomputer for subsequent compilation and analysis. This process was repeated for the 18 elevation angles between 0° and 90°. The number of points analyzed within each elevation zone equalled the midpoint of the zone (e.g., 62 points were analyzed for the zone between 60° and 65°), providing a total of 801 analysis points encompassing 32% of the area of each fisheye photo. Each unit of area sampled by the sensor is nearly equal to any other unit on the photo, since the area occupied by an object on an equidistant lens projection is nearly directly proportional to the angle subtended by the object. That is, the fisheye lens provides an equiangular projection onto a flat surface in which the radial distance (or area) is directly proportional to the angular altitude above the horizon (Anderson 1971).

Our computerized analysis system calculates both the percentage of sky visible (P_Φ, expressed in decimal form) and the average probability of diffuse radiation penetration (X). Vegetative cover, or the percentage of sky obscured by vegetation, may be expressed as $1 - P_\Phi$. Knowing the probability of direct solar and diffuse radiation penetration is important for assessing how overstory vegetation affects such radiation conditions. Diffuse radiation is more uniformly distributed than direct radiation and is therefore a better predictor of radiation flux conditions in and beneath vegetative canopies. Measurements of direct solar radiation are influenced by the angle of light penetration through gaps in the canopy and vary considerably with instantaneous changes in climatic conditions such as occur on partially sunny days.

To calculate P_Φ and X, a clear negative is first analyzed to determine the cover value for a fully closed overstory canopy (100% cover). The results are then stored in the microcomputer. Analyzing a clear negative also corrects for error introduced by nonuniform light emanating from the projector (e.g., the center of the projection is brighter than the edge) and the light transmission properties of the film. Percent sky (P_Φ) is then determined by taking the ratio of the readings from the actual fisheye image to the reading of the clear negative. Analysis of low contrast images requires a calibration that establishes the gray-level threshold for a canopy cover of 100%. This is accomplished by moving the light sensor to a portion of the canopy image estimated to be 100% canopy cover and recording the light intensity at this point. This estimated value is then adjusted with the value obtained from the clear negative and becomes the threshold level for distinguishing between cover and gaps in the canopy.

For each image, values of P_Φ are summed over the elevation zones to provide an estimate of percent sky:

$$\text{Percent sky} = \frac{\sum_{\Phi_1}^{\Phi_N} P_\Phi}{N}$$

The probability of diffuse radiation penetrating the overstory plant canopy can be calculated from the following equation (Jones and Campbell 1979, Miller 1981):

$$\text{Probability of diffuse radiation } (X) = 2\Delta\Phi \sum_{\Phi_1}^{\Phi_N} (P_\Phi \sin\Phi \cos\Phi)$$

where

$\Delta\Phi$ = elevation zone increment (e.g., 5° increments in this study) in radians
N = number of elevation zones (e.g., 18 in this study)
Φ = elevation zone
P_Φ = average probability of radiation penetrating at each elevation zone
$\sin\Phi$ = corrects the cosine response for incoming radiation (i.e., perpendicular radiation has higher intensity than oblique radiation)
$\cos\Phi$ = corrects for the solid angle subtended by vegetation (because objects toward the center appear smaller than they actually are).

Computer programs are available for: (1) estimating plant canopy cover and percent sky, (2) determining the probability of diffuse radiation penetration, and (3) analyzing low contrast images with a gray-scale discriminator system. A program is also being developed for plotting solar tracks to determine the direction, duration, and quantity of direct solar radiation.

TESTING AND VALIDATION OF THE METHOD

To validate the computer analysis, a comparison was made with manual analysis. Six fisheye photographs representing a wide range of canopy coverage were analyzed manually by three different observers. Negatives of the images were projected by a slide projector onto an equal area grid with 80 cells. For each cell of the grid, the percent sky was estimated by eight cover classes (0%; trace—5%; 5–25%; 25–50%; 50–75%; 75–95%; 95–99%; 100%). The same photographs were then analyzed by the computer method.

No significant difference ($P \leq 0.05$) was found between the mean estimates of percent sky determined by manual analysis for each photograph, and the mean estimates determined by the computer analysis. The average time required to analyze a photograph and compute the percent sky was 15 min for the manual method and 5 min for the computer method that included the calibration for a canopy gray-level threshold. However, the manual analysis provided only a single estimate of the entire image, whereas the computer analysis provided additional estimates for each of eighteen 5° elevational zones and also calculated the probability of diffuse radiation penetration.

The precision of the computer analysis method was estimated by analyzing the six different photographs three times. For a single computer operator, the mean standard error of the estimate of percent sky for the three trials was 0.6%. When the three different operators analyzed each of the six photographs one time, the mean standard error of the estimate of percent sky was 1.4%. The error introduced by different operators depends upon how well they standardize the calibration procedure of the 100% cover gray level and upon the variation in the gray levels within the image.

Another potential source of error in the use of canopy photographs results from variation in exposure of the photograph in the field. A test of this source of error was made using Kodalith High Contrast Ortho film and Kodak Plus-X film. At six different sites, for each film type, 5 different exposures were taken by bracketing 2 f-stops on either side of the desired exposure. The estimate of percent sky from the computer analysis for both films was found to increase linearly with increasing aperature. The mean change in the estimate of percent sky, based upon a least squares analysis, was 2.7%/f-stop (S.E. $\pm$ 0.5) for the Plus-X film and 3.5%/f-stop (S.E. $\pm$ 0.4) for the High Contrast Ortho film. These results indicate the importance of standardizing the exposure procedure in the field for both films and caution against comparing photographs taken with different exposure procedures or different film types.

We found no reason to recommend the use of one film type over another; both have advantages and disadvantages. The Kodalith High Contrast film results in an image almost entirely of two gray levels, black for the sky and white for the canopy in the negative image, which is highly desirable for the computer analysis. However, the film is typically set at a low ASA film speed and may not give good results on windy days with slow shutter speeds. Because it produces essentially a binary image, the high contrast film masks variation in canopy gray tones and results in loss of some fine branch detail in images of tall forest canopies, which may not be desirable for some applications of fisheye photography. Thus, the reader is cautioned that Kodalith film can produce varying results in detail, depending on exposure and distance to the subject (Pittaro 1979). One exposure setting may not accommodate the detail of both lower and upper branches in tall forest canopies where branches protrude at many heights along the stem. However, this is not a problem in brush canopies.

Lower contrast films, such as Kodak Plus-X, can be exposed to give relatively high contrast images and can be shot at faster shutter speeds. Such film can also be exposed to retain gray-level variation in canopies and is also less likely to cause loss of fine branch detail. However, because Plus-X is more sensitive to variations in gray level (Pittaro 1979), it is also more sensitive to areas of reflection off canopies, which can cause considerable error in the estimate of percent sky from the computer analysis. Thus, it is essential that field exposures be made under gray skies or near sunrise or sunset.

UTILIZING FISHEYE PHOTOGRAPHY

The primary value of fisheye photography is that many field points can be easily sampled in order to assess both the variability and average canopy and radiation conditions of a site. As a research tool, fisheye photographic analysis provides an accurate, reproducible method of characterizing understory light conditions, levels of competition, and canopy architecture (Figure 1). As a management tool, fisheye photos are an effective aid for training field crews to make more accurate ocular estimates of vegetative cover. They also provide a quantitative method for stratifying reforestation units according to the severity of plant competition, thereby facilitating silvicultural prescriptions. In wildlife management, canopy photographs may be useful in estimating thermal cover for evaluation of habitat potential.

The initial setup costs approach $3,000 (1986 retail prices) for the camera, fisheye lens, light meter, tripod, microcomputer, and related accessories. The efficiency and accuracy of this automated system probably justifies its acquisition, especially if large numbers of photographs must be analyzed.

Factors associated with the photographic process may restrict the utility of fisheye photography. To avoid sunflares and reflectance, the conditions and periods when a photograph can be taken are limited. Error can result if fisheye photographs are improperly exposed. Establishing a gray-level threshold to discriminate between sky and cover can alleviate this problem to some degree. Yet, setting gray-level thresholds is somewhat arbitrary. One solution is to statistically sample and group gray tones into frequency distributions to separate sky from cover. However, such techniques are time consuming and often inadequate for poorly exposed photographs of low contrast with numerous reflections. The edge or the horizon of the fisheye image is sometimes difficult to locate, thus resulting in misalignment during analysis. This is due to the slope or surrounding vegetation on the image edge which obscures light, resulting in a virtually clear and unexposed edge. This problem can be easily overcome by visually aligning the image with care.

The sample perimeter may also affect results. Fisheye photographs provide 180° hemispherical coverage. Distant objects, such as mountains and tall timber that lie above the level of the camera, may appear in the image, even though they have relatively little influence on the immediate plant environment because they are so distant. Eliminating such objects by using higher zenith angles in the analysis may improve correlations between canopy conditions and conifer stand performance (Lakso 1976, Miller 1981). In other cases, such as when vegetation encroaches upon seedlings after site disturbance, using lower zenith angles toward the horizon may give better results.

Despite these limitations, the use of fisheye photography in forest and wildlife management is an accurate, documentable, and efficient way to assess plant cover and the radiation environment. Most of the limitations in utilizing fisheye photographic analysis can be overcome by: (1) using one film type only and knowing the properties of the film, (2) carefully controlling exposures, (3) taking photographs under overcast conditions, (4) standardizing film development procedures, (5) correcting for perimeter effects, and (6) calibrating the analytical equipment properly.

LITERATURE CITED

Anderson, M. C. 1964. Studies of woodland light climate. 1. The photographic computation of light conditions. J. Ecol. 52:27–41.

Anderson, M C. 1971. Radiation and crop structure. P. 416–466 *in* Plant photosynthetic production manual of methods (Z. Sestak, ed.). Dr. W. Junk Publ., The Hague, The Netherlands.

Brown, H. E. 1962. The canopy camera. USDA For. Serv. Rocky Mt. For. & Range Exp. Stn. Pap. 72.

Johansson, T. 1985. Estimating canopy density by the vertical tube method. For. Ecol. Manage. 11:139–144.

Jones, A. J., and G. S. Campbell. 1979. Machine analysis of fisheye photographs for assessment of radiation penetration in plant canopies. A paper presented before the West. Soc. Soil Sci., June 6, 1979. Moscow, Idaho. 7 p.

Lakso, A. N. 1976. Characterizing apple tree canopies by fisheye photography. Hortic. Sci. 11:404–405.

Lakso, A. N. 1980. Correlations of fisheye photography to canopy structure, light climate, and biological responses to light in apple trees. J. Am. Soc. Hortic. Sci. 105:43–46.

Miller, G. P. 1981. Analysis of radiant environment in forest canopies: Technique and application. M.S. Thesis, Wash. State Univ., Pullman. 36 p.

Olsson, L., K. Carlsson, H. Grip, and K. Perttu. 1982. Evaluation of forest-canopy photographs with diode-array scanner OSIRIS. Can. J. For. Res. 12:822–828.

Pittaro, E. M., ed. 1979. Suppl. No. 162, Section 3: Eastman Kodak Co. P. 1–119 *in* Photo lab index, M&M lifetime edition: The cumulative formulary of standard recommended photographic procedures. Morgan & Morgan, Inc., Dobbs Ferry, NY.