A Method for Estimating the Stand Density in an Even-aged Pure Stand Using Hemispherical Photography

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ABSTRACT

We propose a method for estimating the stand density in an even-aged pure stand on a flat slope by hemispherical photography. This method is an application of the method for estimating the stand density proposed by Suzuki, i.e., distance method, and the method for estimating canopy-gap size using two photographs taken at two different heights. First, we assume a homogeneous tree height within an even-aged pure stand on a flat slope, and the straight and vertical axes of all stems. At a sample point selected from the stand randomly, two hemispherical photographs are taken with the vertically mounted camera equipped with a fish-eye lens at two different heights. Next, the radial distances between the center of the hemispherical image and the tip position of tree having the third-largest elevation angle (third-smallest zenith angle) are measured on each photograph taken at the two different heights. By substituting the measured radial distances into the relationship between radial distance and zenith angle of the fish-eye lens used, the elevation angles between camera and tip of the third-nearest tree can be obtained. Using these values of elevation angle, the distance from the photographic sample point to the third-nearest tree can be geometrically computed, and then the stand density can be estimated by substituting the computed distance into the equation of Suzuki’s distance method.

Keywords: distance method, forest measurement, even-aged pure forest, hemispherical photograph

INTRODUCTION

The hemispherical photography has been widely used to estimate the canopy characteristics such as leaf area index as well as the potential direct and diffuse light through discrete canopy openings (e.g., Hale and Edwards, 2002; Inoue et al., 2004b; Yamamoto et al., 2010). The hemispherical photography has the advantage of providing a permanent record of the canopy openings, light environment and stand condition. As a permanent record, the photographs can be studied using existing analytical methodology and would serve for future studies as method are further developed and refined (Rich, 1990). An inexpensive high-resolution digital camera that can equip with an exclusive fish-eye lens has recently become available, and it enables us to reduce the cost, time, and labor for film processing and image scanning (Inoue et al., 2004b). The digital technique also has the advantage that the images can be viewed immediately in the field, and retaken if necessary (Hale and Edwards, 2002).

Despite of the many advantages, so far the application of hemispherical photography to the estimation of common stand attributes, i.e., stand density, mean tree height, mean diameter at breast height, total basal area and stand volume, has been superficial (cf., Clark, 2009). Such application can replace the field work for the measurement of attributes by the estimation from image analysis of hemispherical photographs. The photographs can be taken and analyzed by a single observer, and therefore the use of photography would be less labor-intensive than the traditional field work. In addition, the photographs can be reanalyzed by the other researchers as well as the observer that took them as many times as needed.

In this study, we proposed a method for estimating the stand density, or the number of trees per unit area, in an even-aged pure stand on a flat slope using hemispherical photography. Suzuki (1965) proposed a method for estimating the stand density by measuring the average distance between a randomly selected sample point and the third-nearest tree from the point (hereafter called “distance method”). Yamamoto (2000) also devised a method for estimating the canopy-gap size from two photographs taken with a vertically mounted camera at different heights, and successfully...
estimated the canopy-gap sizes in the Cryptomeria japonica D. Don plantations. The method presented here is an application of these two methods to the hemispherical photography. The objective of this paper is to propose a theory and methodology; and thus the accuracy and precision of the proposed method in the field are the beyond the scope of this study.

METHODOLOGY

To estimate the stand density rapidly and easily, Essed (1957) proposed a distance method and Suzuki (1965) modified this distance method as follows: Now suppose that a tree is randomly distributed over a stand. Let \( x_s \) be the distance from a randomly selected sample point in a stand to the third-nearest tree. Denoting the average of \( x_s \) measured at some sample points in the stand as \( X_3 \), the stand density, i.e., number of trees per hectare, \( \rho \) can be estimated by the following equation:

\[
\rho = \frac{100}{X_3^2} \left( \frac{15}{16} \cdot \frac{15}{16} \cdot \frac{8789}{X_3^2} \right). \tag{1}
\]

To obtain the value of \( X_3 \), the hemispherical photographs are used in the method presented here. The common fish-eye lens used in hemispherical photography is designed to be a simple polar projection (e.g., Frazer et al., 2001; Inoue et al., 2004a). In this projection formula, the relationship between radial distance (the distance between the center of hemispherical image and a given point on the photograph) \( r \) and zenith angle \( \theta \) is given by

\[
\theta = kr \tag{2}
\]

where \( k \) is a constant, which varies with the radius of hemispherical image \( R \), i.e., \( k = \pi / 2R \). Eq. 2 can be rewritten in terms of the elevation angle \( \alpha \) as follows:

\[
a = \frac{\pi}{2} - kr. \tag{3}
\]

For this method, we assume a homogeneous tree height within an even-aged pure stand on a flat slope, and the straight and vertical axes of all stems. This assumption has been used in the vertical angle count sampling developed by Hirata (1955). At a sample point selected from the stand randomly, two hemispherical photographs are taken with the vertically mounted camera equipped with a fish-eye lens at two different heights, \( h_1 \) and \( h_2 \). Under this condition, the third-nearest tree from the sample point has the third-largest elevation angle (or the third-smallest zenith angle) between camera and tree tip. The elevation angle can be estimated from the radial distance at the position of the tip on the hemispherical photograph. For this reason, the radial distances between the center of hemispherical image and the tip of tree having the third-largest elevation angle can be estimated. Hence, Eq. 3 allows us to estimate the stand density, \( \rho \), in the stand.

CONCLUSIONS

In this paper, we presented a method for estimating the stand density in an even-aged pure stand on a flat slope. This method would provide a simple and rapid mean for evaluating the stand density in even-aged pure stands. The accuracy and precision will be heavily dependent upon whether the tree tip can be recognized on the hemispherical photographs. Hence, although it may be inappropriate to apply to estimate the stand density in very dense stands, it might be useful in estimating stand density in scarce stands or deciduous ones such as larch spp. In a later study, the accuracy, precision and working efficiency of the proposed method should be verified.

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