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Estimating forest leaf area using cover and fullframe fisheye photography: Thinking inside the circle

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Abstract

This study compares circular fisheye photography and destructive leaf area index (L) estimation with two alternative indirect methods for estimating L in broad-leaved forest: fullframe fisheye photography and cover photography. Fullframe fisheye photography differs from circular fisheye photography in that the images have a reduced field of view; the zenithal range of 0°–90° extends to the corners of the rectangular image, roughly doubling image resolution compared to circular fisheye images. Cover images are obtained by pointing a 70 mm equivalent focal length lens (in 35 mm format) straight upwards. Cover and L were measured in twelve stands of a 17 years old *Eucalyptus marginata* forest that had been planted at four initial densities: 625, 1250, 2500 and 10,000 trees per hectare. L, from destructive sampling, averaged between 2 and 2.4 for stands planted at between 1250 and 10,000 trees ha^{-1} but was only 1.3 for the stands planted at 625 trees ha^{-1}. Cover photography provided good indirect estimates of L assuming a spherical leaf distribution, except in the stands with 10,000 trees ha^{-1}. These trees appeared to have a more horizontal leaf angle based on the calculated zenithal extinction coefficient for those stands (~0.7). Rapid and automated analysis of cover images using WinSCANOPY 2006 yielded similar results to manual image analysis using Adobe Photoshop. Estimates of L from fullframe fisheye photography were better correlated with L from destructive sampling than L estimated from circular fisheye photography, but neither performed as well as cover photography. Photographic methods that use a single threshold to separate sky and foliage appear less sensitive to the camera's gamma function than methods that use a two-value threshold. Higher resolution (>8 megapixel) cameras and better lenses, may further improve L estimation using fullframe fisheye photography. We recommend that cover photography be used for routine L estimation in broadleaf forest until it is demonstrated that fisheye methods can provide similar accuracy.
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Keywords: Hemispherical photography; Light extinction coefficient; *Eucalyptus marginata*; Foliage cover; Stand density; Leaf area index

1. Introduction

Despite the well-established importance of leaf area index (L) for modelling plant growth and water use, indirect methods for measuring it are poorly developed. Harvesting of trees for direct measurement of leaf area is labour intensive, time-consuming, destructive, and sometimes impractical or dangerous owing to poor access and difficult terrain (Bréda, 2003; Chen et al., 1997; Kucharik et al., 1999; Macfarlane et al., 2000; Macfarlane et al., 2007). With the release of affordable digital cameras, fisheye photography (Anderson, 1964) has become a rapid and cheap method for estimating

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L. However, fisheye photography is sensitive to photographic exposure, the gamma function of the film or camera, the method of pixel classification and image resolution (Blennow, 1995; Cescatti, 2006; Chen et al., 1991; Jonckheere et al., 2005; Macfarlane et al., 2000; Macfarlane et al., 2007; Wagner, 2001; Wagner and Hagemeier, 2006).

The importance of exposure control is well documented (Chen et al., 1991; Macfarlane et al., 2000; Zhang et al., 2005) and the two-value threshold method has been proposed as a means of reducing the effects of exposure on L_t derived from fisheye photographs (Wagner, 2001). Macfarlane et al. (2007) showed that large errors can result from analysing fisheye images using a two-value threshold if the images are not corrected for the gamma function of the camera; Wagner (1998) illustrated the importance of correcting images for the gamma function of chemical films when using the two-value threshold method. The gamma function of a digital camera describes the relation between the actual light intensity during photography and the resulting brightness value of the pixel (Cescatti, 2006; Wagner, 1998); an image that accurately reproduces actual light intensities would have a gamma value of 1.0. Digital cameras typically have gamma values between 2 and 2.5 (Cescatti, 2006); Leblanc (2006) found that the most popular camera used for digital fisheye photography, the Nikon Coolpix 4500, has a gamma function of 2.2, and Macfarlane et al. (2007) obtained good results using this gamma value. The importance of variation in the gamma function has not been investigated for single threshold pixel classification methods.

In theory, by measuring the gap fraction at multiple zenith angles it is possible to simultaneously determine both L and the foliage angle distribution, and this should be the biggest advantage of fisheye methods. However, similarly to previous studies (Chen and Black, 1991), Macfarlane et al. (2007) found that the foliage angle distribution calculated from fisheye photography was as much affected by canopy structure as by the actual foliage angle distribution, despite corrections for foliage clumping. It is possible that this is the result of the lower resolution of fisheye images and resulting poorer estimates of crown porosity obtained from fisheye images; Blennow (1995) observed that higher resolution images have fewer ‘‘mixed pixels’’, which could obscure small gaps within canopies resulting in underestimation of canopy porosity and calculation of an inaccurate gap size distribution. The resolution of fisheye images can be easily improved by using fullframe fisheye images instead of circular images. Unlike circular images, in which the entire canopy hemisphere (zenithal range of 0–90°) is contained in a circle that occupies about half the pixels inside a rectangular image, fullframe fisheye images have a reduced field of view such that the zenithal range of 0°–90° extends to the corners of the rectangular image, roughly doubling image resolution.

Fullframe, or nearly fullframe, fisheye photography has been used in the past to estimate L or below canopy light environments (Anderson, 1981) with 35 mm film format cameras. However, analysis of fullframe fisheye images has not been possible with the suite of software packages that have been readily available for the past decade (Hemiview, Hemiphot, GLA, DHP-TRACWin, CANEYE and WinSCANOPY). Hence, digital hemispherical photography was limited to the Nikon Coolpix range of cameras and their fisheye converters, or a very few expensive digital SLR cameras with 35 mm CMOS or CCD, and the few compatible 8 mm fisheye lenses that were available. In 2006, the ability to apply the same gap fraction inversion methods applied to circular fisheye images to fullframe images was implemented in WinSCANOPY (Regent Instruments, Ste-Foy, Quebec). This greatly increased the range of cameras and lenses that can be used for fisheye photography and provided an opportunity to compare fullframe and circular fisheye photography using digital photographic methods.

As another alternative to circular fisheye photography, Macfarlane et al. (2007) tested digital photographs of the canopy obtained by pointing a 70 mm (35 mm format equivalent) focal length lens upwards to estimate crown cover (% ground covered by the vertical projection of solid crowns) and foliage cover (% ground covered by the vertical projection of foliage and branches). After correcting for foliage clumping they estimated L from the Beer–Lambert law. The method outperformed fisheye photography in that study (Macfarlane et al., 2007) and had many advantages over fisheye photography. It could be applied during daylight hours, cover images were of much higher resolution than fisheye images and, thus, less sensitive to photographic exposure; sky luminance was more even, and the narrow viewing angle and the rectangular shape of the cover images was better suited to small rectangular experimental plots. The disadvantages of the method were that the image analysis was not automated, although it was simple and rapid, and the method required an assumed zenithal light extinction coefficient (k). An automated method of analysing cover images has recently been incorporated in WinSCANOPY (Regent Instruments, Ste-Foy, Quebec), which, unlike

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