Agricultural and Forest Meteorology 195–196 (2014) 102–107

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Increasing the precision of canopy closure estimates from hemispherical photography: Blue channel analysis and under-exposure

Anthony Brusa[a,*], Daniel E. Bunker[b]

[a] Department of Biological Sciences, Rutgers-Newark, The State University of New Jersey, 195 University Avenue, 435 Boyden Hall, Newark, NJ 07102, United States

[b] Department of Biological Sciences, 433 Colton Hall, New Jersey Institute of Technology, University Heights, Newark, NJ 07102-1982, United States

ARTICLE INFO

Article history:
Received 7 October 2013
Received in revised form 1 May 2014
Accepted 3 May 2014
Available online 27 May 2014

Keywords:
Hemispherical photography
Canopy characteristics
Canopy closure
Exposure
Color channel
Plant canopies

ABSTRACT

Accurate measurement of canopy structure is fundamental to the fields of ecological modeling and restoration. A large number of methods exist for estimating the structure of forest canopies, with widely varying costs and effectiveness. Hemispherical photography has been in use for several decades, and the rise of lower-cost consumer grade digital SLR cameras has expanded the availability of this technique. We examine two improvements to the hemispherical photography technique for estimating canopy closure: computer-based blue channel analysis and under-exposing images. Photographs taken in the field (without a filter) showed much lower variation in the blue channel than in red or green channel of the same images. We found a higher variance in canopy closure measurements due to over-exposure of images, while images with automatic light metering and under-exposed images remained consistent. We conclude that under- or normal exposure combined with blue channel analysis together minimize variability and maximize the precision of canopy closure estimates. Results from hemispherical photography were comparable to the widely used LAI-2200, supporting hemispherical photography as a viable, low-cost alternative.

1. Introduction

Forest canopy cover is a key feature of forests worldwide, positively affecting both the functioning of the forest canopy itself and also strongly impacting environmental conditions in the forest understory. Accurate assessment of forest canopies and their effect on the understory environment are necessary for numerous ecological and agricultural efforts, from estimates of net primary productivity (NPP) to conservation and restoration of understory species. Analysis of forest canopies has proven useful in accelerating hurricane recovery and invasive species control (Uriarte et al., 2005; Malik et al., 2010), and for monitoring water and carbon cycles (Leblanc and Chen, 2001). Canopy characteristics are important to these fields because light availability is frequently the limiting resource in understories (Finzi and Canham, 2000). Canopy characteristics also strongly predict NPP and other import forest ecosystem functions (Bartemucci et al., 2006; Comita et al., 2009; Dube et al., 2001; Finzi and Canham, 2000; Gravel et al., 2010; Jelaska et al., 2006; Knowles et al., 1999; Kobe, 1996; Kobe et al., 1995; Pacala et al., 1996; Sudderth et al., 2012; Uriarte et al., 2005). Canopy openness is a strong predictor of seedling survival in early stages of ecosystem recovery (Comita et al., 2009). Other work has also shown that light availability is an important factor in models that predict sapling mortality (Kobe et al., 1995), canopy growth (Beaudet and Messier, 2002; Sonnentag et al., 2012), and regeneration (Comita et al., 2009; Romell et al., 2009), indicating a long term role in forest dynamics. Canopy structure provides much needed insight into forest ecosystem function, highlighting the importance of accurate quantification of forest canopy characteristics.

Because forest canopies impact forest communities and ecosystems in numerous ways, several metrics have been developed to describe canopy characteristics. Leaf Area Index (LAI) provides information about the physical structure of a canopy, and thus is well suited to applications where canopy functions such as NPP need to be estimated or modeled. In contrast, when the objective is to evaluate environmental conditions at a particular point or set of points in the understory, direct measurement of light availability at particular points in the understory may be more

* Corresponding author. Tel.: +1 973 482 3282.
E-mail address: abrusa.rutgers@gmail.com (A. Brusa).

http://dx.doi.org/10.1016/j.agrformet.2014.05.001

Table 1
Common canopy variables and their definitions.

Variable	Physical measurement
Canopy closure	Proportion of sky blocked by canopy at all angles from a single point
Canopy coverage	Proportion of sky blocked by canopy at vertical angle from multiple points
Diffuse non-interceptance	Amount of light, both direct and indirect, received from the sky
Gap fraction	Proportion of open space in a canopy
Leaf area index	Amount of foliage that a vertical line through the canopy will intersect
Light metering	Amount of photonic energy from the sun

appropriate. Metrics of understory light availability include canopy closure, canopy coverage, diffuse non-interceptance (DIFN), and gap fraction (Table 1). Multiple methodologies exist for quantifying understory light availability (Table 2), including the LI-COR LAI-2200 (Li-Cor Inc., Lincoln, NE, USA), spherical densiometers, photosensitive diazo paper, LIDAR devices, and hemispherical photography (Bao et al., 2008; Ferment et al., 2001; Lang et al., 2010). In the present paper we are focused on improvements to hemispherical photography techniques that quantify canopy closure, defined as the proportion of sky which is blocked by the canopy when viewed at all angles from a single point in the understory (Jelaska et al., 2006; Jennings et al., 1999). Canopy closure has been shown to be a better estimator of solar radiation levels than canopy coverage (Table 1), particularly in north facing sites (Jelaska et al., 2006).

The central premise of hemispherical photography is that the specialized lens captures an image that spans a 180° arc, and when pointed vertically can capture all possible angles of incoming light, making it well suited for estimating canopy closure. These images are then digitally processed to differentiate sky from canopy. Hemispherical photographs have been used alongside other techniques and found to provide comparable measurements in many studies (Bao et al., 2008; Bellow and Nair, 2003; Chianucci and Cutini, 2013; Ferment et al., 2001; Guevara-Escobar et al., 2005; Hopkinson and Chasmer, 2007; Leblanc and Fournier, 2005; Pueschel et al., 2012; Sasaki et al., 2008; Seidel et al., 2012; Takashima et al., 2006). While hemispherical photography has been used for decades with film cameras (e.g., Chen et al., 1991), use has risen in recent years due to the ready availability of high quality digital cameras on the consumer market. Analysis of hemispherical photographs on computers is greatly facilitated by the digital format, as film images must be scanned before analysis, resulting in the potential degradation of image data, which can directly impact the results of sky to canopy separation techniques (Jelaska et al., 2006). As optics, digital cameras, and computational methodologies continue to improve, techniques for canopy analysis can be refined and improved.

Our investigation here refines hemispherical photographic techniques by maximizing the precision of canopy closure estimates.

2. Hypotheses

2.1. Hypothesis 1: post-processing analysis of the blue channel of a hemispherical photograph reduces the variance of canopy closure estimates

Canopy closure is the proportion of sky that is blocked by the canopy at a given point in the understory. Thus, accurate and precise discrimination of sky and canopy is critical to effective quantification of canopy closure. In hemispherical photography, the incoming rays are captured in individual pixels, which are subsequently categorized as either sky or canopy based on light intensity, and the ratio of these counts is used to derive a canopy closure value. The foundation of these methods rests on a sorting algorithm that isolates light and dark regions of the sky by setting a threshold based on a histogram of light intensity across all pixels. The higher the contrast between these parts of the image, the more confident we can be in the resulting measurements. The best images then would be ones that generate an image histogram with a strongly bimodal distribution. A properly exposed, high contrast image will yield similar results regardless of the algorithm used in setting a threshold.

This separation can be enhanced by evaluating color channels of an image, and taking advantage of the difference between the colors of plant pigmentation and the sky. The sky has a high transmittance of blue for the majority of the day, while most plants have pigments that strongly absorb both blue and red light (Lariguet and Dunand, 2005). This means that evaluation of the blue channel of images should have a high degree of contrast. Practical applications of this can already be seen, as the use of color filters in the field is quite common (Ferment et al., 2001; Jonckheere et al., 2005; Leblanc and Chen, 2001; Zhang et al., 2005). The majority of cameras available today are digital, allowing direct access to color channel information, precluding the need for a color filter in the field. Our investigation was to see if these benefits could extended to post-processing techniques of images taken without a filter. We predict that canopy closure estimates from post-processed blue channel images will have reduced variance and thus increased precision of canopy closure estimates.

2.2. Hypothesis 2: under-exposure of hemispherical photographs reduces the variance of canopy closure estimates

We also evaluated the impact of image exposure levels on the reliability of image thresholding. Although this aspect of hemispherical photography has been well studied, the literature remains divided on what the optimum exposure technique should be. Zhang

Table 2
Techniques for assessing tree canopy variables, associated costs, and restrictions.

Method	Measurement type	Cost	Weather restrictions	Other notes
LIDAR	LAI, Gap Fraction, Gap Size Distribution, FIPAR, Crown Closure, distance	$100,000	Any light condition, avoid rain	"active" system, doesn't require light to penetrate canopy
LAI-2000	LAI, DIFN, Gap Fraction, Crown Closure	$9000	Avoid direct sunlight (corrections can be made)	Has a built-in 490 nm filter
Hemispherical photos	Gap Fraction, Gap Size Distribution, can compute LAI, directional closure (sun tracks), Crown Closure	$1000	Uniform sky works best, avoid rain	
Spherical densiometer	Sky openness, extremely rough estimates	$100		Unreliable, based on human counting
Diazo paper	General light exposure (amount of radiation received)	Varies		Price depends on area covered
TRAC	Gap Fraction, Gap Size Distribution	$3000	Requires strong sunlight	Direct light measurement, requires transect, time intensive