Automated procedures for estimating LAI of Australian woodland ecosystems using digital imagery, Matlab programming and LAI / MODIS LAI relationship

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Abstract

Leaf area index (LAI) is one of the most important variables required for modelling growth and water use of forests. The implementation an approach to estimate LAI from digital pictures (LAI_D) has recently been advanced in Australia using digital image capture and gap analysis, which employs a novel methodology (Macfarlane et al 2006). This technique uses upward-looking wide-angle digital photographs to capture canopy LAI_D and analyses these images using gap fraction analysis at a single zenith angle (0^o – 57^o), using commercial image processing software. After implementing this technique in Australian evergreen *Eucalyptus* woodland, we have improved the picture analysis method from a time consuming manual technique to an automated procedure. Furthermore, in this paper, we compare MODIS LAI values with digital image LAI values for a range of woodlands in Australia.

We used Matlab 7.4 (The Mathworks, Inc), to batch process numerous upward-looking digital images (at least 50 per site) to estimate LAI (LAI_M) from different woodland sites within New South Wales, Australia. The blue band (450 – 495 nm) of each image was extracted and explored to identify a threshold between foliage and sky. In the procedure, the selection of a suitable luminance value from the blue band histograms can be fully automated for numerous images or manually generated for each image. After assigning a suitable blue layer threshold, the image is transformed into a binary image for gap analysis.

The gap analysis is performed by automatically dividing each binary image into nine sub-images. From each sub-image, the program counts the total of pixels corresponding to sky (S) and leaves (L). A big gap is considered when the ratio S/L ≥

0.75 is met for each sub-image. In this case, the pixel count for sky (S) is added to the big gap count for that particular image. If this ratio is not met for a specific sub-image, the pixel count contribution to the total big gap count of that particular image is equal to zero.

The fractions of foliage projective cover **(f_f)**, crown cover **(f_c)** and crown porosity **(Φ)** are calculated from Mcfarlane et al (2006) as:

$$\mathbf{f_c\ (\%)} = 100 * (1 - \text{large gap pixels / total pixels}) \qquad \mathbf{[1]}$$

$$\mathbf{f_f\ (\%)} = 100 * (1 - \text{total gap pixels / total pixels}) \qquad \mathbf{[2]}$$

$$\mathbf{\Phi} = 1 - f_f/f_c \qquad \mathbf{[3]}$$

LAI_M is calculated from Beer's Law, assuming an extinction co-efficient (k) of 0.5 as follows:

$$\mathbf{LAI_M} = -f_c \ln\Phi / k \qquad \mathbf{[4]}$$

and the clumping index at the zenith, **$\Omega(0)$**, is calculated as follows:

$$\mathbf{\Omega(0)} = (1-\Phi) \quad \ln(1- f_f) / \ln(\Phi) / f_f \qquad \mathbf{[5]}$$

The same equations [1 – 5] are used to calculate LAI_D using Adobe PhotoShop® 7.0 and the methodology described in Macfarlane et al (2006). The automated maximum threshold value using Matlab resulted in a good average LAI_M compared to the averaged LAI_D for five sites (Figure 1a) ($y = 1.01LAI_D$; $R^2 = 0.95$, using four sites). When patchy clouds are present in the pictures, the manually generated threshold was more appropriate to obtain accurate individual LAI_D from single pictures when compared to LAI_D ($y = 0.951LAI_D$; $R^2 = 0.98$, from 50 pictures; Hornsby site only, data not shown). A Matlab code was also developed to acquire images using a high resolution web cam attached to a laptop for in-field real-time digital image acquisition and analysis.

Following the capture of digital images and determination of LAI_D in eight examples of *Eucalyptus* woodland, we assessed the relationship between LAI_D and MODIS LAI products for each of the ground measurements. We extracted the 8-day 1 km MODIS LAI (collection 4) data for New South Wales from the MODIS distributed archive and imported these into a GIS. Ground sampling sites were established along a precipitation gradient (450 – 1400 mm) in New South Wales, Australia. 8-day LAI values for ground sampling stations (of approximately 1 ha) were extracted using a data-drill. At each ground sampling station, canopy LAI (LAI_D) was calculated from at least 50 randomly collected images from the 1 ha stations within the 1 km MODIS pixel. Individual modeled MODIS LAI values for each sampling occasion were selected from the 8-day image closest to the date of the LAI_D sampling event. Although seasonal variations in MODIS LAI was apparent at each sampling site (e.g range from LAI 1 to 4 in wet sites), the ground sampling events coincided with periods when MODIS LAI closely approximated LAI_D. The ground sampling excluded the contribution of understorey LAI, and was conducted during the dry season when the contribution of the understorey would have been at its minimum. The regression LAI_D = 0.8822 MODIS LAI + 0.0701(R^2 = 0.85) describes the relationship between LAI_D and MODIS LAI for eight sites.

We concluded that digital image acquisition; coupled with Matlab data analysis capacities, provide a rapid, robust, cheap and simple method for determining the LAI of tree canopies. Furthermore, we conclude that for evergreen woodland, where seasonal understorey growth is limited due to drought, the MODIS LAI product provides a useful surrogate for LAI_D. This is probably not true when understorey LAI makes a large contribution to the MODIS LAI.

Keywords: Eucalyptus forest; Leaf area index; Digital photography; Matlab; Remote sensing; MODIS LAI

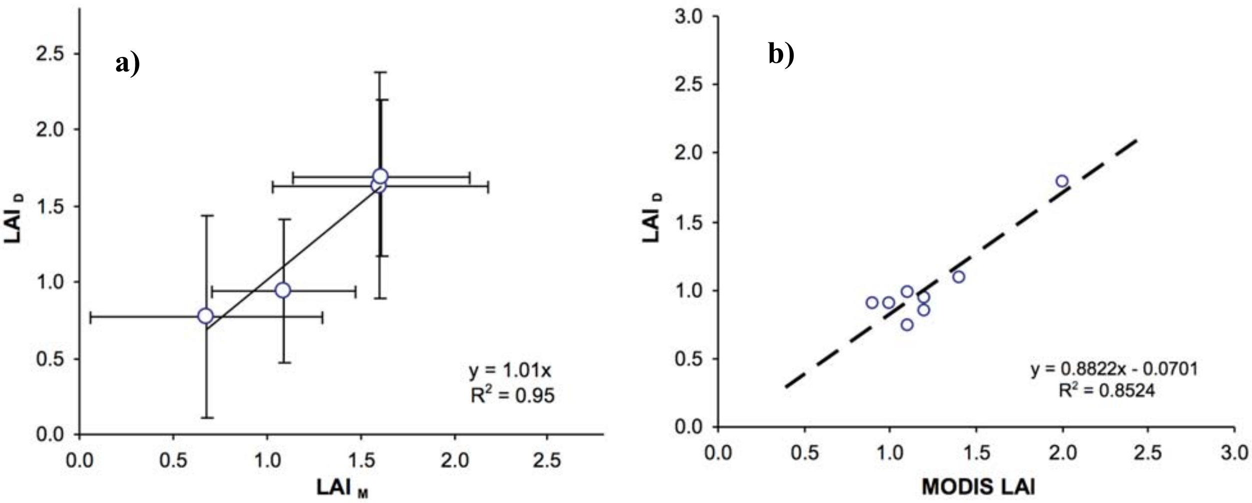

Figure 1: a) Relationship between LAI_M and LAI_D for four NSW sites. **b)** Relationship between LAI_D and MODIS LAI for eight NSW sites.