# Characterising understorey Plant Area Index with TLS

Phil Wilkes[1,2], Mathias Disney[1,2], Cecilia A. L. Dahlsjö[3] and Yadvinder Malhi[3]

[1]University College London, Department of Geography, Gower Street, London, WC1E 6BT, UK
Email: {p.wilkes, mathias.disney}@ucl.ac.uk

[2]NERC National Centre for Earth Observation (NCEO)

[3]Environmental Change Institute, School of Geography and Environment, University of Oxford, South Parks Road, Oxford OX1 3QY, UK
Email: {cecilia.dahlsjo; yadvinder.malhi}@ouce.ox.ac.uk

## 1. Introduction

Leaf Area Index (LAI), measured as one half of the total green leaf area per unit horizontal ground surface area, is a key metric for estimating biophysical structure and function; as such LAI is listed as an Essential Climate Variable. LAI can be difficult to quantify, particularly in forest environments, where e.g. saturation, leaf angle distribution, leaf clumping and the inability to separate leaf and wood confound accurate estimation. A number of methods have been developed to estimate LAI such as leaf litter traps, digital hemispherical photography and terrestrial laser scanning (TLS) (Woodgate *et al.* 2015) .

The understorey vegetation layer in forests plays an important role in overall forest function, for example providing habitat for small mammals. The understorey layer is also dynamic and can respond rapidly to changes in light environment e.g. caused by tree fall or in response to defoliating pathogens. Quantifying understorey LAI can be difficult owing to measurement difficulty and for this reason is often overlooked.

Here we present methods (and preliminary results) that use TLS to estimate understorey Plant Area Index (PAI) - no distinction is made between wood and leaf material - that is applied across fifteen plots in Wytham Woods, UK. PAI estimates were computed by modifying the "hinge angle" method of Jupp *et al.* (2008); further, to increase the sampled area, the TLS instrument was mounted on a pneumatic mast.

## 2. Methods

A multi-year project has been established in Wytham Woods, UK, to monitor the woodland response to canopy decline as a result of ash dieback. Fifteen 40 m x 40 m plots were installed through the forest; 5 plots are ash dominant where the ash trees have been girdled to simulate a rapid decline in the tree canopy (winter 2020/21), 5 plots are ash dominant control and 5 plots are non-ash dominant control (predominantly *Acer pseudoplatanus* and *Fagus sylvatica*).

TLS has so far been conducted twice at the fifteen plots (summer and winter); further acquisitions are planned for 2023. Scanning was done with a RIEGL VZ-400 (Horn, Austria) where scans were performed with an angular resolution of 0.04 degrees in an upright position. Scan positions were located along the 4 edges of the plot (to avoid disturbing understorey vegetation and other experimental equipment) and in the centre (Figure 1). The scanner was mounted on a pneumatic mast and pumped to heights of 2 m, 3 m, 4 m and additionally at 6 m in the plot centre (Figure 1); this was done to capture different portions of the plot as well as to reduce operator bias i.e. locating the scanner in an open area. Considering only the 120° - 125° zenith ring (see below), and scanning as in Figure 1, resulted in ~15% of the total plot area being captured. If only a 2 m tripod had been used <2% of the plot would have been captured.

To compute estimates of PAI, the "hinge angle" method of Jupp *et al.* (2008) was modified. First vertically resolved angular dependent gap probability $P_{gap}$ was derived:

$$P_{gap}(\Theta, z) = 1 - \frac{\sum w_i (w_i < z, \Theta)}{N(\Theta)} \quad (1)$$

where $z$ is height below the scanner, $\Theta$ is the zenith ring interval, $w$ is a weighting dependent upon the number of targets intercepted by each outgoing pulse and $N$ is the total number of outgoing pulses. PAI as a function of height can then be derived as:



Published in: Markus Hollaus, Norbert Pfeifer (Eds.): Proceedings of the SilviLaser Conference 2021, Vienna, Austria, 28–30 September 2021.
Technische Universität Wien, 2021. DOI: 10.34726/wim.1861
This paper was peer-reviewed. DOI of this paper: 10.34726/wim.1862

$$PAI(z) \approx -1.1 log(P_{gap}(\Theta))(2)$$

To approximate the hinge angle of 57.5° Jupp *et al.* (2008) analysed Θ = [55°, 60°]. Here, to estimate PAI below the scanner, the polar opposite zenith ring where Θ = [120°, 125°] was extracted. To not conflate vegetation and the ground surface in undulating terrain, a digital elevation model (DEM) with a resolution of 0.5 m was created from all data (i.e. not limited to a zenith ring) from all scan heights at a single scan position. This also allows for a more accurate estimate of vegetation height to be computed.

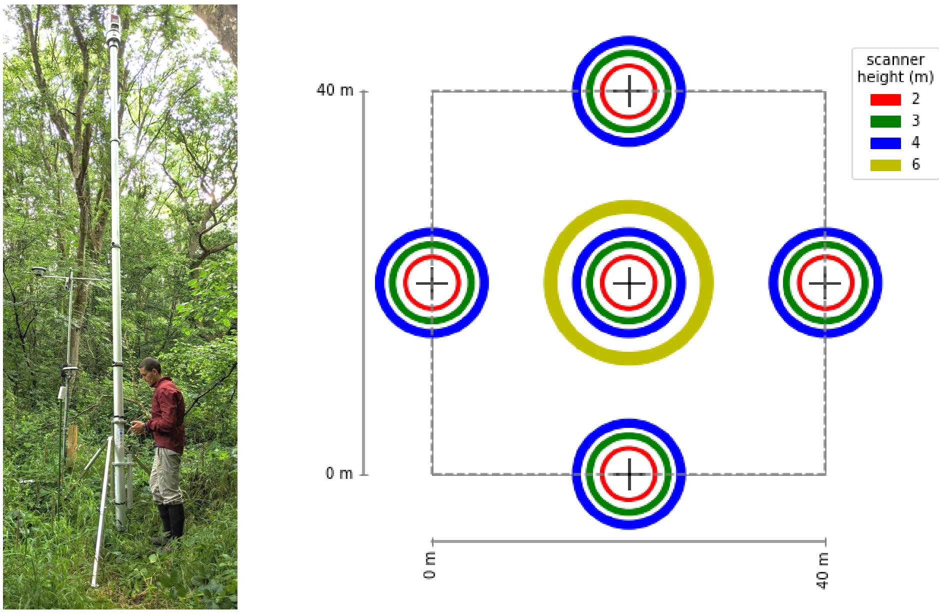


Figure 1. Pneumatic mast extended to 6 m with RIEGL VZ-400 mounted on top (left) and location of scan positions in a plot with area scanned by zenith ring [120°, 125°] at different heights.

## 3. Results and Discussions

Vertically resolved PAI are presented in Figure 2 where profiles have been truncated between 0.1 - 2 m above ground. Maximum plot-level understorey PAI was 2.02 recorded at Plot 1B in summer, a minimum value of 0.09 was recorded in winter for Plot 1C. There is a clear distinction between ash dominant and non-ash plots where the former has a dense understorey. It is suggested that this is a result of ash canopies being less dense (evident in full canopy PAI curves), therefore allowing more light to penetrate to the understorey below that result in abundant bramble thickets. PAI was on average ~50% of summer PAI in winter and the understorey layer was noticeably lower in height, particularly in the bramble dominated ash plots (e.g. ash (control) plot 3 in Figure 2).

The benefits of using the mast is an open question. Preliminary results would suggest that PAI values do not differ between scans captured at different heights owing to the homogeneity of the plots. The additional time and expense of mast hire and deployment therefore may not be worthwhile; however, if only scanning from 2 m, care must be taken to not bias the sample by scanning in a clear area and ensure scanning is conducted on, or inside, the plot boundary.

Other methods for measuring understorey PAI have not been trialled so far in this experiment. Leaf litter traps are also installed but are at a height of 1 m above ground level; installing litter traps at ground level could be problematic e.g. damage due to animal activity. PAR sensors are installed at heights of 0.3 m and 3 m on weather stations at the plot centres and could be used as a reference data set; larger samples (at different heights) could be gathered using an LAI sensor such as LiCOR LAI-2200. However, TLS is not dependent on light conditions and has been shown to be more precise than other methods in forest environments (Calders *et al.* 2018).

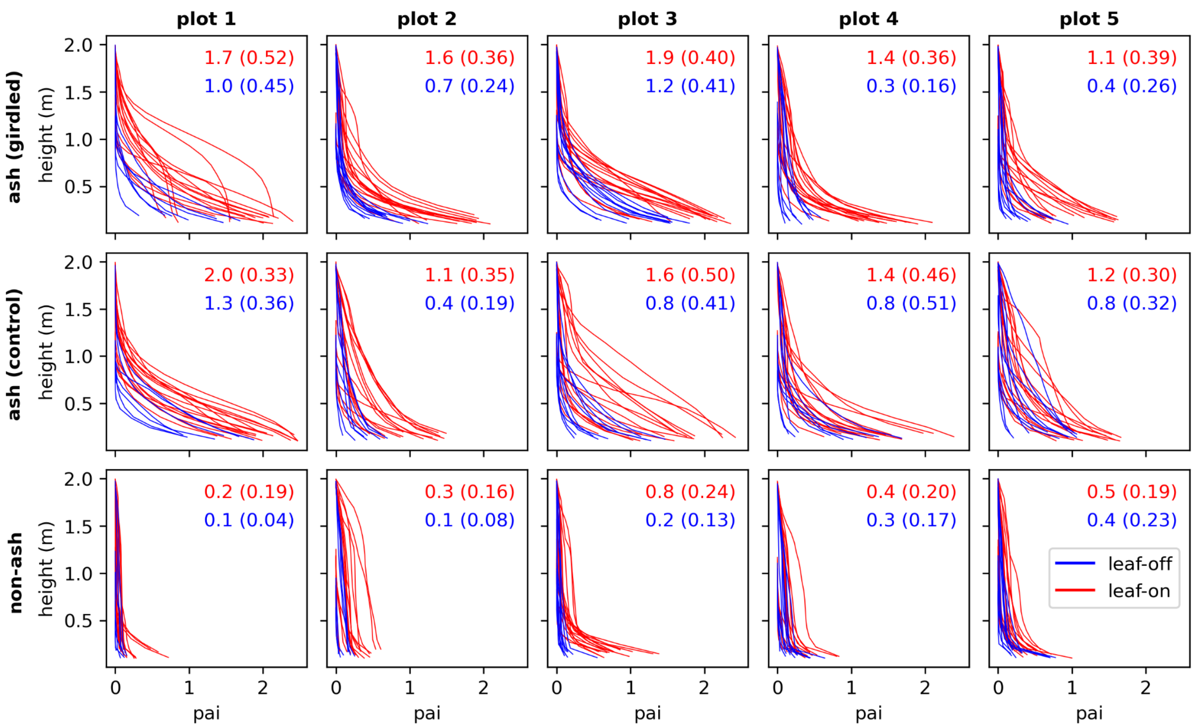


Figure 2. Vertically resolved PAI curves for each scan captured. Profiles have been truncated between 0.1 - 2 m and normalised so that PAI is 0 at 2 m. Values in red and blue are mean (standard deviation) PAI for summer and winter respectively.

## Conclusions

This paper presents results from TLS scanning of forest understorey conducted in Wytham Woods, UK. A modified version of the “hinge angle” approach of Jupp *et al.* (2008) appears to be successful for characterising vertically resolved understorey PAI. Further scanning of the plots will allow an analysis of the impacts of changing light conditions on understorey vegetation following ash dieback.

## Acknowledgements

This work is funded by NERC (NE/T007648/1). PW and MD also acknowledge funding from NERC National Centre for Earth Observation (NCEO). YM acknowledges funding from the Jackson Foundation. The authors would also like to thank the foresters of Wytham Woods. particularly for rescuing us from the mud!

## References

Calders, K., Armston, J. D., Newnham, G. J., Herold, M., & Goodwin, N. R. (2014). Implications of sensor configuration and topography on vertical plant profiles derived from terrestrial LiDAR. Agricultural and Forest Meteorology, 194(August), 104–117. https://doi.org/10.1016/j.agrformet.2014.03.022

Calders, K., Origo, N., Disney, M., Nightingale, J., Woodgate, W., Armston, J., & Lewis, P. (2018). Variability and bias in active and passive ground-based measurements of effective plant, wood and leaf area index. Agricultural and Forest Meteorology, 252(September 2017), 231–240. https://doi.org/10.1016/j.agrformet.2018.01.029

Jupp, D. L., Culvenor, D. S., Lovell, J. L., Newnham, G. J., Strahler, A. H., & Woodcock, C. E. (2008). Estimating forest LAI profiles and structural parameters using a ground-based laser called “Echidna”. Tree Physiology, 29(2), 171–181. https://doi.org/10.1093/treephys/tpn022

Woodgate, W., Jones, S.D., Suarez, L., Hill, M.J., Armston, J.D., Wilkes, P., Soto-Berelov, M., Haywood, A., Mellor, A., 2015. Understanding the variability in ground-based methods for retrieving canopy openness, gap fraction, and leaf area index in diverse forest systems. Agric. For. Meteorol. 205, 83–95.