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Characterising phenological changes in North West forests using terrestrial laser scanning: some preliminary results.

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Abstract

The value of phenological data in climate change research has been recognised by the scientific community, as phenology plays a crucial role in global warming studies. The significance of two-dimensional information on vegetation composition provided by optical remotely sensed data to identify phenological changes in vegetation canopies is well established. Nevertheless, the three-dimensional (3D) characterisation of vegetated environments by means of light detection and ranging (lidar) sensors, both at ground-based and airborne levels, has recently been recognised by environmental scientists. Lidar data can contribute with accurate 3D information on biophysical properties of vegetation characteristics, including canopy cover, leaf area index (LAI) and vegetation height. The objective of this study is to test a quantitative, accurate and repeatable method for characterising phenological changes in forest canopies, by using multi-temporal terrestrial laser scanner (TLS) data. The study is being conducted in Delamere Forest, located in Cheshire, North West England. Lidar data on vegetation structure were acquired for seven sampling plots, two broad-leaved and five conifer stands, between March 2008 and April 2009. Canopy directional gap fraction distributions were derived from TLS datasets, and compared with estimates derived from hemispherical photographs recorded coincidentally with the TLS measurements. The results indicate the potential of TLS to characterise canopy structure. This characterisation will lead to further assessment of the sensitivity of lidar sensors to seasonal variations in forest canopies.

Keywords

terrestrial laser scanning, forest, phenology, Delamere Forest

Introduction

Changes in climate have the potential to impact on vegetation distribution and growth, and in order to predict future responses of the biosphere to a changing climate it is necessary to quantify variations in seasonal characteristics of plant ecosystems. Remote sensing science has made significant advances in mapping, modelling, and aiding our understanding of ecosystems. Typical applications of remote sensing involve using images from passive optical sensors, such as the satellite-based sensors Landsat and MODIS, and these have proved to be adequate for many ecological applications, such as land cover mapping (Lefsky *et al.*, 2002). Nevertheless, these sensors produce only two-dimensional (2D) images, which cannot fully characterise the three-dimensional (3D) structure of vegetation canopies, particularly for forests.

Light detection and ranging (lidar) is a remote sensing technology that can be used to enhance the ability to remotely sense biophysical properties of vegetation (Lefsky *et al.*, 2002). Specifically, Terrestrial Laser Scanners (TLS) have the potential to measure the 3D structure of forest canopies (Danson *et al.*, 2007). TLS can be used for fast acquisition of dense 3D datasets of entire surfaces, which includes the magnitude of the intensity values of the laser return signals based on the reflectivity of the object being scanned (Clawges *et al.*, 2007). Applications of TLS in forestry have focussed on the rapid semi-automatic determination of stand characteristics like tree density, height, and girth (Danson *et al.*, 2007). Watt and Donoghue (2005) worked on the application of a ground-based laser scanning system for providing quantitative tree measurements in densely stocked plantations forests in northern England. This study concluded that TLS data could be used to measure tree diameter and density accurately. Moreover, diameter estimates were obtained by Henning and Radtke (2006), showing high agreement between the lidar-derived estimates and manual measurements of bole sections made below the base of the live crown. It is worth mentioning that despite advances in vegetation analysis using lidar systems, the distribution of laser pulses returned from within forest canopies is still not fully understood. In addition, the intensity measurements are rarely used (Höfle and Pfeifer, 2007), and the information that can be derived from them is yet to be determined. Chasmer *et al*. (2006) suggests that estimates of forest structural variables using lidar data can be improved by obtaining a better understanding of how laser pulse returns are triggered within vegetated environments.

Aim of this research project

The aim of this research is to investigate the potential of TLS to characterise phenological changes in UK forests. The research will investigate the seasonal canopy changes for a range of tree species found in Delamere Forest, Cheshire, North West England, and determine what biophysical information can be derived from TLS data. It is expected that this research will provide a better understanding of how laser pulse returns are activated within forest canopies and how they are affected by biophysical canopy properties and data acquisition parameters. This paper describes some initial findings of this research.

Study site

The study site for this research is Delamere Forest, the largest area of woodland in Cheshire, managed by the Forestry Commission and located 40 km south west of Manchester, (British National Grid reference 354800 370400). The forest comprises homogeneous stands of Scots pine and larch, as well as mixed stands of oak and birch. Field data on vegetation structure have been acquired at seven sampling plots, comprising two broad-leaved and five conifer forest stands, surveyed by differential GPS and marked to allow repeat measurements. Figure 1 shows the locations of the seven sampling plots, which are described in Table 1. The sampling plots were selected based on site inspections made between December 2007 and February 2008, and the information obtained from the stock maps of Delamere Forest provided by the Forestry Commission.

Four deciduous and three evergreen stands were selected for this research. The deciduous stands are locations 2 and 3 which are composed of broad-leaved stands of Birch (*Betula spp*), Oak (*Quercus spp*) and Sweet chestnut (*Castanea sativa*) species planted in 1899, and locations 5 and 6 comprising coniferous Japanese larch (*Larix kaempferi*) planted in 1981 and 1976 respectively. The evergreen stands comprise Scots pine (*Pinus sylvestris*) and Corsican pine (*Pinus nigra var maritima* – location 1) planted in 1945, Corsican pine (*Pinus nigra var maritima*) and Weymouth pine (*Pinus strobus* – location 4) planted in 1970, and a young Corsican pine stand (*Pinus nigra var maritima* – location 7) planted in 1990.

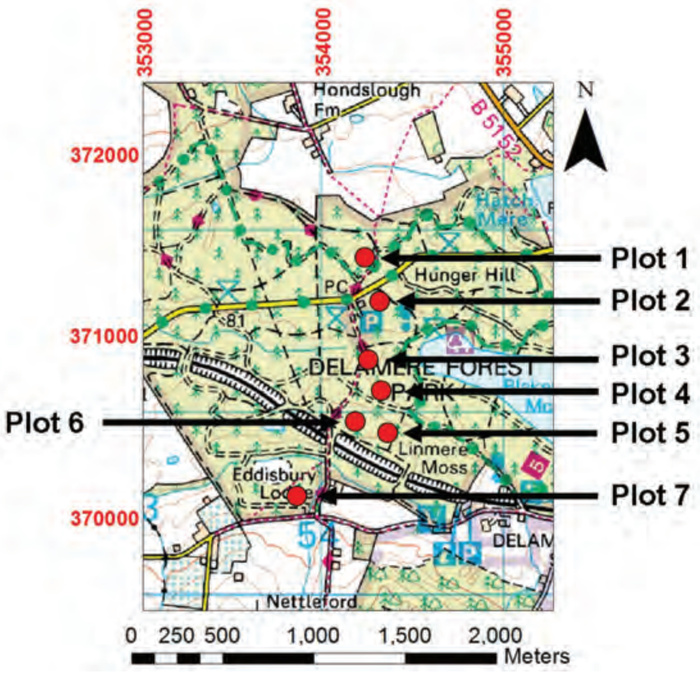

Figure 1: The locations of the seven sampling plots in Delamere Forest are indicated by the red circles. (Crown copyright/database rights 2010. An Ordnance Survey/Edina supplied service).

Table 1: Description of sampling plots in Delamere Forest.

Conifer stands			
Location	Tree species	Deciduous	Evergreen
1	Scots pine (*Pinus sylvestris*), Corsican pine (*Pinus nigra var maritima*)		■
4	Corsican pine (Pinus nigra var maritima), Weymouth pine (*Pinus strobus*)		■
5	Japanese larch (*Larix kaempferi*)	■	
6	Japanese larch (*Larix kaempferi*)	■	
7	Corsican pine (*Pinus nigra var maritima*)		■

Broad-leaved stands			
Location	Tree species	Deciduous	Evergreen
2	Birch (*Betula spp*), Oak (*Quercus spp*), Sweet chestnut (*Castanea sativa*)	■	
3	Sweet chestnut (*Castanea sativa*)	■	

Data collection

Data collection campaign

An extensive data collection campaign was carried out at Delamere Forest between early 2008 and early 2009 using two TLS (Riegl LMS-Z390i and Riegl LMS-Z210i). The campaign started in early March 2008 in order to capture the "leaf-off" stage of the deciduous stands. Data were then collected at monthly intervals during the growing season and into the beginning of the leaf-off stage for the deciduous trees. Table 2 summarises the dates of data collection. The main objective of this campaign was to acquire sufficient datasets that would eventually allow the determination of what biophysical properties could be estimated from TLS and produce a characterisation of seasonal variations in forest canopies.

Table 2: Dates of terrestrial laser scanner data collection.

Year: 2008	Riegl LMS – Z390i	Riegl LMS - Z210i
March	19th	
April	11th, 28th	3rd
May	23rd	13th
June	19th	
July	4th, 22nd	22nd
September	9th	
October	10th	
December	18th	

Year: 2009	Riegl LMS – Z390i	Riegl LMS - Z210i
March		19th
April	3rd	

Terrestrial laser scanners characteristics

The scanners (Riegl LMS-Z390i and Riegl LMS-Z210i) used in the data collection campaign are rugged sensors designed for the rapid and accurate acquisition of three-dimensional images by using a two-axis beam-scanning mechanism and a pulsed time-of-flight laser range finder. The reason for using two scanners in this research is to compare canopy directional gap fraction estimates derived from data recorded by two sensors, which use lasers of different wavelengths and have different beam divergences, in order to obtain a better understanding of the interaction of lasers with vegetation canopies. A technical comparison of the sensors used is shown in Table 3.

Table 3: Technical comparison of the sensors used.

Laser Scanner	Beam divergence	Wavelength	Angular sampling resolution used	Maximum range
LMS-Z210i	2.7 mrad	900nm	0.108°	650m
LMS-Z390i	0.3 mrad	1550nm	0.1°	400m

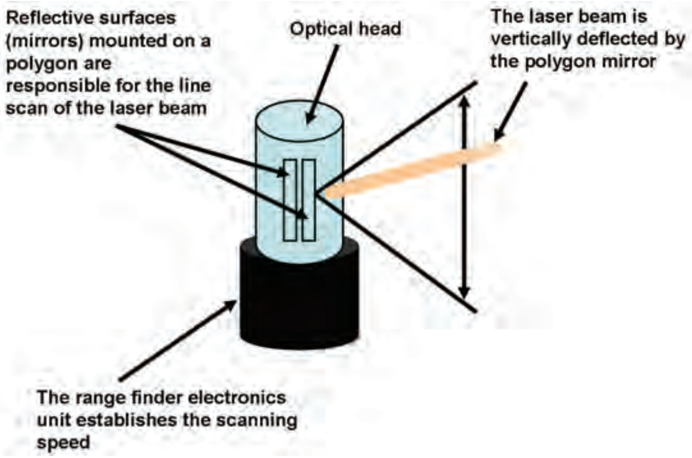

Figure 2: Diagram of TLS components, including the range finder electronics unit, the reflective surfaces and the optical head.

The main components of a TLS include the range finder electronics unit, a number of reflective surfaces responsible for the line scan of the laser beam, and the optical head (Figure 2). As shown in Figure 3, the rotation of a polygon mirror inside the optical head in the zenithal direction produces what is called the line scan measurement, whereas the rotation of the optical head in the azimuthal direction produces the frame scan measurement. The TLS configuration, as well as the data acquisition, visualisation and manipulation are carried out through the use of software provided by the manufacturer, which can be executed on any standard computer. In order to characterise phenological changes, the study was carried out using the Riegl LMS-Z390i, as it has a narrow beam which is assumed to be more effective at interacting with the canopy.

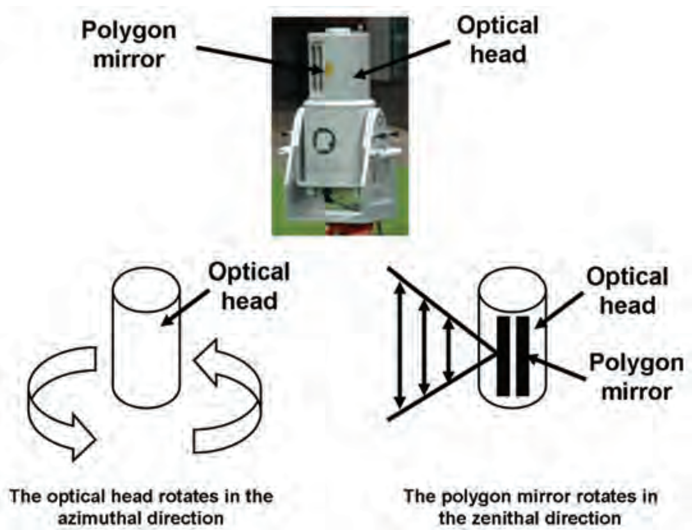

Figure 3: Line scan measurements are produced by the rotation of a polygon mirror in the zenithal direction, while the rotation of the optical head in the azimuthal direction produces frame scan measurements.

Data collection method

The terrestrial data collection campaign was carried out following the methodology proposed by Danson *et al*. (2007). Spatially and temporally coincident TLS data and digital hemispherical photographs were acquired at each of the seven fixed sampling locations in the study site. Hemispherical photography is currently recognised as the principal technique available for creating a permanent record of forest canopy structure (Danson *et al*., 2007). Hemispherical photographs were taken at each sampling location using a Nikon D70s digital camera with a calibrated hemispherical lens orientated to look directly upwards. Once the photograph were taken, the TLS was mounted on a levelled surveying tripod at an inclination angle of 90°. A single scan was taken with a line scan angle of 80° and a frame scan angle of 360°, using an angular sampling resolution of 0.1° in line and frame scan directions, and recording the first return. The scanner was then rotated 90° and a second orthogonal scan was taken in order to fully characterise the canopy structure situated above the sensor. Figure 4 shows the Riegl LMS-Z390i mounted on a surveying tripod and ready to scan at location 6 (deciduous stand). The 28V battery necessary to power the TLS and the laptop required to operate it are also shown in the figure. A laser scanner image corresponding to a scan taken by the Riegl LMS-Z390i is shown in Figure 5.

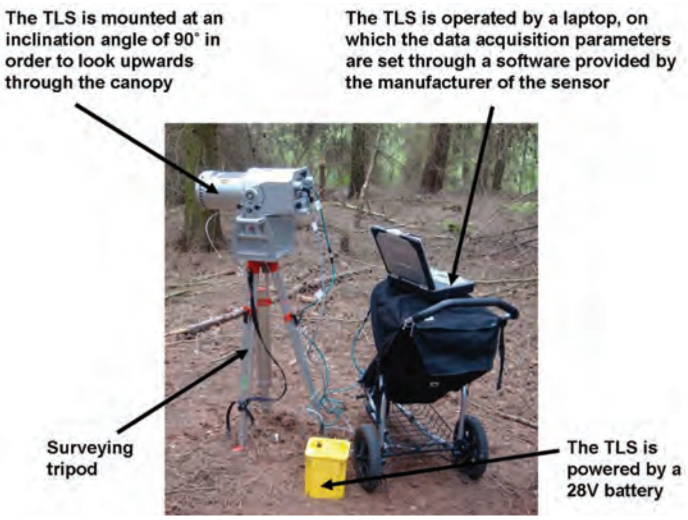

Figure 4. TLS mounted for data acquisition.

Calculations of canopy gap fraction

A gap in the canopy occurs when a laser beam is emitted in a given direction, and there is no corresponding return signal detected by the sensor. Danson *et al*. (2007) developed a TLS model to compute gap fraction distributions derived from field data on forest canopy structure, which has been used to compute the corresponding estimates from data collected at the sampling plots chosen in the study site for this research. The model compares the expected number of laser shots in all directions with the measured number of laser hits in order to determine gap fraction distributions. The calculation of the number of laser shots in all directions was based on the scanning geometry and the data acquisition parameters used to obtain the TLS datasets, including the angular sampling resolution and the line and frame scan angle ranges, which are shown in Tables 4 (Riegl LMS Z210i) and 5 (Riegl LMS Z390i).

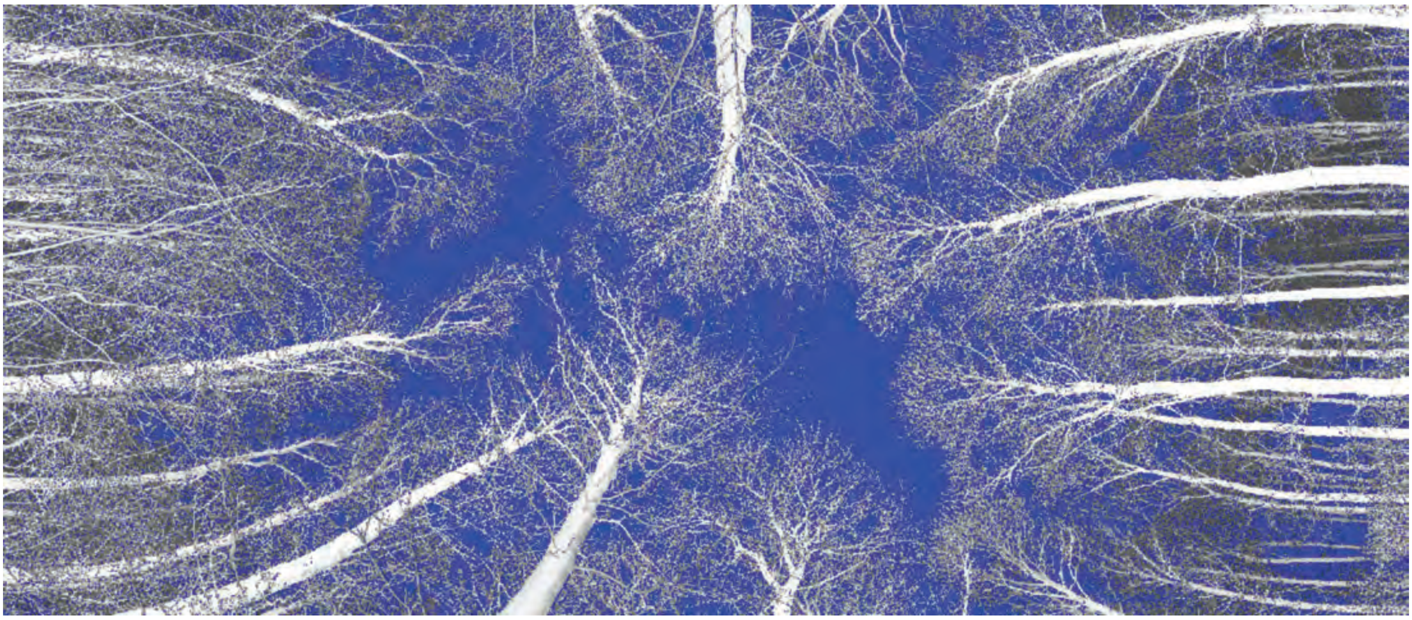

Figure 5: TLS image corresponding to a scan taken at sampling plot 3 (Sweet chestnut – Castanea sativa). Date of acquisition: 11th April 2008.

Table 4. Data acquisition parameters used with the Riegl LMS-Z210i.

Data acquisition parameters	
Line scan angle (zenithal direction)	Frame scan angle (azimuthal direction)
Start angle: 50° Stop angle: 129.704° Angular sampling resolution: 0.108°	Start angle: 15° Stop angle: 345.372° Angular sampling resolution: 0.108°

Table 5. Data acquisition parameters used with the Riegl LMS-Z390i.

Data acquisition parameters	
Line scan angle (zenithal direction)	Frame scan angle (azimuthal direction)
Start angle: 50° Stop angle: 129.9° Angular sampling resolution: 0.1°	Start angle: 0° Stop angle: 360° Angular sampling resolution: 0.1°

Results

Figures 6 and 7 show the gap fraction computed from TLS data acquired using the Riegl LMS-Z390i at two deciduous (locations 2 and 3) and two evergreen (locations 1 and 4) sampling plots on 11th April and 10th September respectively. Estimates shown in Figures 6 and 7 indicate that results derived from measurements taken in April are higher than estimates computed from data collected in September for deciduous stands (locations 2 and 3). The difference is primarily related to the conditions observed during the spring greening and summer growth phases respectively. As regards the evergreen plots (locations 1 and 4), a slight difference in magnitude can be noticed between the corresponding gap fraction distributions calculated. This indicates that TLS may be sensitive to changes in canopy biomass at relatively small scales, which will be subject of further investigations.

Figures 8 and 9 show gap fraction distributions derived from both TLS measurements and hemispherical photograph acquired on 11th April 2008 for a Corsican pine plot (Pinus nigra var maritima). Although relatively similar patterns can be detected between the shapes of the curves, a lack of agreement in terms of the magnitudes observed can be seen, which indicates that gap fraction distributions are underestimated by calculations derived from TLS datasets in comparison with the corresponding results obtained from hemispherical photographs.

The underestimation observed in Figures 8 and 9 has to do with the fact that when a laser beam hits a spot in the canopy, it may not be fully occupied by canopy elements. However, irrespective of the area of the beam that is not occupied, no gap is detected. This means that the empty region of the beam will not be taken into account for the computation of gap fraction distributions. Consequently, only laser signals travelling through the canopy without encountering canopy elements will be considered to characterise gaps in the canopy.

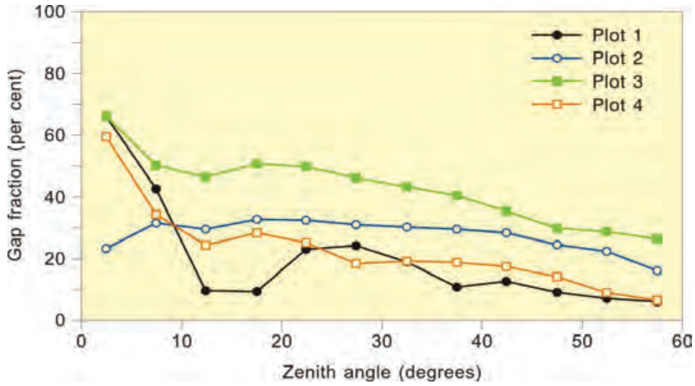

Figure 6: Canopy gap fraction estimates from TLS data acquired on 11th April 2008. The results correspond to plot 1 (Corsican pine – Pinus nigra var maritima), plot 2 (Oak – Quercus spp; Sweet chestnut – Castanea sativa), plot 3 (Sweet chestnut – Castanea sativa), and plot 4 (Corsican pine – Pinus nigra var maritima; Sweet chestnut – Castanea sativa).

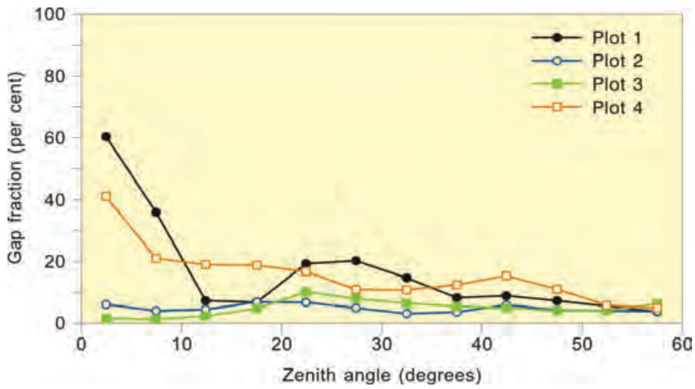

Figure 7: Canopy gap fraction estimates from TLS data acquired on 10th September 2008. The results correspond to plot 1 (Corsican pine – Pinus nigra var maritima), plot 2 (Oak – Quercus spp; Sweet chestnut – Castanea sativa), plot 3 (Sweet chestnut – Castanea sativa), and plot 4 (Corsican pine – Pinus nigra var maritima; Sweet chestnut – Castanea sativa).

The results corresponding to gap fraction distributions obtained so far indicate that intensity values recorded by TLS may hold relevant information to identify empty areas in laser beams partially occupied by canopy elements, and thus could be considered in the computations. The importance of intensity values was noticed by a study conducted by Danson *et al*. (2008), which suggests that intensity calibration is necessary to use this information to improve gap fraction calculations. However an understanding of how intensity values are triggered within forest canopies is first required, which will be subject of further investigations.

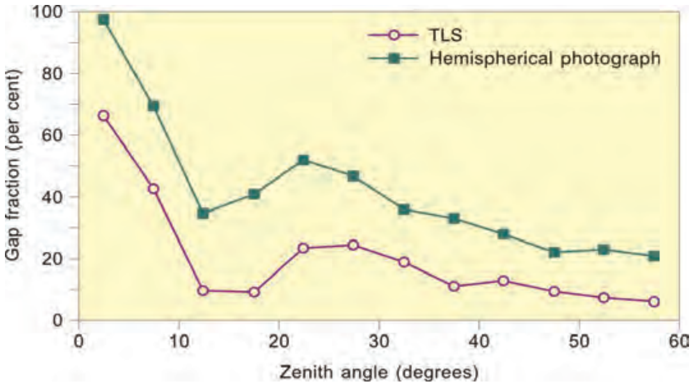

Figure 8: The open circles refer to gap fraction estimates derived from TLS measurements, whereas the green squares indicate estimates obtained from hemispherical photographs. The corresponding datasets were acquired at sampling plot 1 (Corsican pine – Pinus nigra var maritima). Date of acquisition: 11th April 2008.

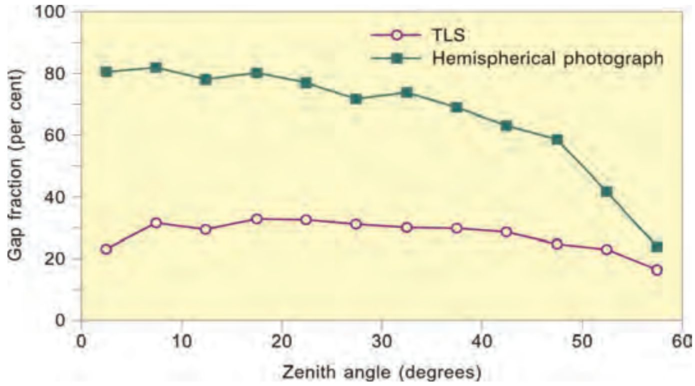

Figure 9: The open circles refer to gap fraction estimates derived from TLS measurements, whereas the green squares indicate estimates obtained from hemispherical photographs. The corresponding datasets were acquired at sampling plot 2 (Oak – Quercus spp; Sweet chestnut – Castanea sativa). Date of acquisition: 11th April 2008.

Conclusions and future research activities

As there are relatively few studies that have used TLS to measure vegetation structure, particularly temporally, new information on 3D characterisation of forest canopies and phenological changes is expected from multi-temporal profiles of canopy cover and LAI at each of the sampling plots derived from the datasets acquired so far. The preliminary results presented are the starting point of an intensive data processing and analysis phase that will be carried out during the next twelve months. Different research topics will be addressed, including the kind of information that can be inferred from the intensity values recorded by TLS, as well as the sensitivity of this sensor to structural changes in forest canopies. Finally, it is expected to obtain new information related to the interaction of lasers with vegetation from the analysis of the data collected and additional experiments to be conducted using TLS.

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