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Estimation of canopy attributes in beech forests using true colour digital images from a small fixed-wing UAV

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ABSTRACT

Accurate estimates of forest canopy are essential for the characterization of forest ecosystems. Remotely-sensed techniques provide a unique way to obtain estimates over spatially extensive areas, but their application is limited by the spectral and temporal resolution available from these systems, which is often not suited to meet regional or local objectives. The use of unmanned aerial vehicles (UAV) as remote sensing platforms has recently gained increasing attention, but their applications in forestry are still at an experimental stage. In this study we described a methodology to obtain rapid and reliable estimates of forest canopy from a small UAV equipped with a commercial RGB camera. The red, green and blue digital numbers were converted to the green leaf algorithm (GLA) and to the CIE $L^*a^*b^*$ colour space to obtain estimates of canopy cover, foliage clumping and leaf area index (L) from aerial images. Canopy attributes were compared with *in situ* estimates obtained from two digital canopy photographic techniques (cover and fisheye photography).

The method was tested in beech forests. UAV images accurately quantified canopy cover even in very dense stand conditions, despite a tendency to not detecting small within-crown gaps in aerial images, leading to a measurement of a quantity much closer to crown cover estimated from *in situ* cover photography. Estimates of L from UAV images significantly agreed with that obtained from fisheye images, but the accuracy of UAV estimates is influenced by the appropriate assumption of leaf angle distribution.

We concluded that true colour UAV images can be effectively used to obtain rapid, cheap and meaningful estimates of forest canopy attributes at medium-large scales. UAV can combine the advantage of high resolution imagery with quick turnaround series, being therefore suitable for routine forest stand monitoring and real-time applications.

1. Introduction

Accurate estimates of forest canopy are central for a wide range of studies including hydrology, carbon and nutrient cycling, and global change. Leaf area index (L), canopy cover and clumping index are amongst the most widely used canopy attributes. Ground-based methods to estimate these variables include either direct contact (destructive sampling) or indirect optical methods (for a review, see Jonckheere et al., 2004). Generally, both approaches are time consuming and unpractical for large forest areas. In addition, these methods are unsuitable for real-time application such as monitoring wildfire spread or plant disease outbreaks (Anderson and Gaston, 2013). Remotely-sensed information offers a unique way to obtain large scale mapping of forest canopy attributes. In particular, several studies indicated that space-borne sensors can be used to obtain spatially extensive information from landscape to the global scale (*e.g.*, Davi et al., 2006; Turner et al., 1999; Hu et al., 2007; Lamonaca et al., 2008; Pellikka et al., 2009; Prospatin and Panferov, 2013). However, the spatial and temporal resolutions of satellite-based data are often not suited to meet regional or local objectives. New satellite sensors have become operational over the past decade, offering data at finer spatial scale and more respon-

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sive capabilities. Notwithstanding these improvements, high-cost per scene and not profitable revisit time remain significant obstacles for many remote sensing applications. Airborne platforms may theoretically be used to obtain more scale-appropriate data, but they are so expensive to prevent regular time-series monitoring.

Recent technological advances have led to an upsurge in the availability of unmanned air vehicles (UAV). UAVs can combine high spatial resolution and quick turnaround times together with lower operational costs and complexity. However, low-cost and light-weight sensors are required for UAVs, particularly for small-sized vehicles that make use of commercial digital cameras (Hunt et al., 2008). Commercially available sensors like RGB cameras are highly suitable for use with UAV platform but their reliability still need to be accurately verified (Clemens, 2012). Recent studies have tested the use of UAV-derived vegetation indices to monitor canopy attributes of field crops (*e.g.*, Hunt et al., 2005, 2010; Guillen-Climent et al., 2012). The majorities of the adopted indices involve use of NIR bands, because the near infrared portion of the electromagnetic spectrum provides strong information on both the physiological status and the geometric properties of vegetation (Houborg and Boegh, 2008; Breunig et al., 2013). On the contrary, relatively few studies have tested the applicability of UAV-derived vegetation indices based on solely the visible portion of the electromagnetic spectrum (VIs) (*e.g.*, Hunt et al., 2005; Jannoura et al., 2015). Nonetheless, VIs are particularly interesting for UAV applications because they can be obtained from commercial RGB digital cameras; therefore, this option holds great potential for expanding the range of sensors and platforms available for UAV sensing of vegetation.

In this study we tested whether true colour (RGB) digital photography can be used to obtain estimate of forest canopy attributes from unmanned aerial vehicles. For this purpose we used a small fixed-wing UAV equipped with a standard RGB digital camera, which was tested in pure beech stands. Canopy attributes derived from true colour UAV imagery were calibrated against ground estimates of canopy cover and leaf area index, which were obtained from well-established canopy photographic techniques.

2. Material and methods

2.1. Study sites and field data collection

The study was carried out on July 2015 in a mountain forest in Tuscany, Central Italy (Alpe di Catenaia, 43°48′N, 11°49′E; Fig. 1). The climate at the study site was temperate, with warm, dry summers and cold, rainy winters. The mean annual rainfall was 1224 mm, and the mean annual temperature was 9.5 °C.

Ten 0.5–1 ha beech stands were sampled, which were located within a radius of 1 km each other. The stands showed differences in stand density (ranging from 108 to 3324 trees ha^{-1}), basal area (ranging from 14.7 to 45.3 m^2 ha^{-1}) and mean height (ranging from 26.4 to 29.9 m). Species composition in the stands was nearly pure (beech contribution >90% of basal area).

Within each stand, canopy attributes were estimated *in situ* using two canopy photographic techniques (Fig. 2), namely cover photography (DCP) and fisheye photography (DHP), which were used as benchmark to validate UAV-based indices. The two photographic methods were previously calibrated against direct data in beech stands (see Chianucci et al., 2015). All photographs were acquired as ‘fine’ quality and at maximum resolution (2272 × 1704 pixels) jpeg using a Nikon Coolpix 4500. Photographs were collected close to sunrise or sunset at a height of 1 m along a grid of sampling points, following the protocols by Macfarlane et al. (2007) and Chianucci and Cutini (2013) as summarized in Table 1 and described below.

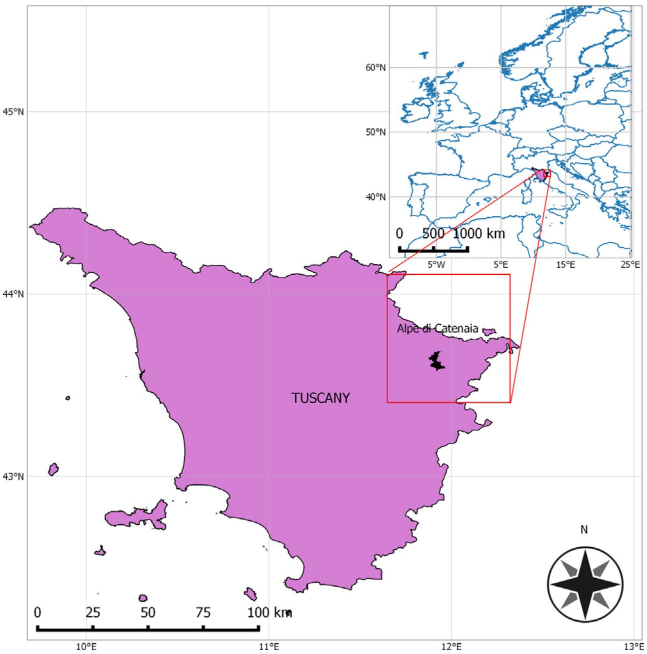

Fig. 1. Location of the study area.

Table 1
Camera setup and processing for fisheye (DHP) and cover (DCP) photography.

Parameters	DHP	DCP
Acquisition:		
Camera	Nikon Coolpix 4500	
Orientation	North	
Lens	FC-E8 fisheye	Fixed
Lens set	F1	F2
Field of view	~180°	~30°
Mode	Manual	Aperture-priority
F-number	5.3	9.6
Exposure	Underexposed	Automatic
Format	Jpeg	
Resolution	2272 × 1704	
Quality	FINE	
Time of day	Close to sunrise (or sunset)	
Analysis:		
Images per stand	9	36
Foliage clumping method	Lang and Xiang (1986)	Chen and Cihlar (1995)
Gamma function	1.0	2.2
Zenith angle range	~0–70°	~0–15°
Zenith angle rings	7	1
Azimuth segments	8	1
Color channel used	Blue	RGB

In each stand, 36 cover images were collected with the fixed lens set to F2, minimum aperture (*F* 9.6), automatic exposure. RGB images were sharpened (medium) and analysed in Winscanopy 2012a (Regent Instruments, Ste-Foy, Quebec, Canada). Two distinct estimates of canopy cover were obtained and used as ground reference for comparison with UAV estimates: foliage cover (f_F), which was calculated as the complement of total gap fraction, and crown cover (f_C), which was calculated as the fraction of pixels that do not lie in between-crowns gaps (Fig. 2), considering between-crown gaps as those exceeding the 0.3% of the image area; this threshold value was set in a previous study (Chianucci et al., 2014a). Foliage clumping Ω(0) was also calculated from gap size distribution (Chen and Cihlar, 1995; as modified by Leblanc, 2002):

$$\Omega(0) = \frac{\ln\left[\overline{P(0)}\right]}{\ln\left[F_{mr}(0)\right]}\frac{\left[1 - F_{mr}(0)\right]}{\left[1 - \overline{P(0)}\right]} \quad (1)$$