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Photographic assessment of overstory and understory leaf area index in beech forests under different management regimes in Central Italy

Short communication

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Abstract. Forest understory may be strongly affected by silvicultural practices such as thinning, which simultaneously modulates the overstory canopy cover and influences the availability of light. However, the understory layer is rarely considered in management decisions, partly because methods to estimate understory leaf area index are poorly developed. In this study we used two different restricted view angle photographic methods to estimate overstory plant area index L_O (zenith cover photography), understory leaf area index L_U (nadir cover photography) and their related canopy attributes (foliage clumping, foliage cover, crown cover, crown porosity). These measurements were performed in beech stands under different management regime. Results from photography indicated that not only overstory but also understory canopy attributes were significantly influenced by forest management. In addition, a significant negative correlation was found between L_O and L_U. We conclude that the photographic methods are effective for monitoring (overstory and understory) canopy status in managed stands, on account of their rapid and not destructive procedures, which allows large scale implementation of the methods.

Keywords: forest understory, plant area index, thinning, *Fagus sylvatica*, cover photography.

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Introduction

Managing forests in ways that sustain biodiversity and ecosystem functioning is a major challenge in modern forestry. As forest management consists of a complex of anthropogenic disturbance, silviculture should be a key factor in explaining plant distribution and diversity in managed forests (Decocq *et al.*, 2004). In particular, forest understory – i.e., the vegetation growing beneath the forest canopy, may be strongly affected by silvicultural practices such as thinning, which simultaneously modulates the (overstory) canopy cover and therefore the availability of different resources, including light, water and soil nutrients (Decocq *et al.*, 2004; Coll *et al.*, 2011). The forest overstory-understory relationships are complex and mutual, but

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are dominated by the strong influence of the overstory structure on e.g. litter, light availability and quality (Messier *et al.*, 1998); hence, overstory canopy structure may play a key role in understory recruitment, establishment, and thus plant diversity. However, studies reporting overstory-understory relationships rarely describe the relationship in terms of leaf (or plant) area index, which is a key canopy attribute. This is mainly motivated because, although methods for estimating overstory leaf area index have received considerable attention in the last decades (for a review, see Bréda, 2003; Jonckheere *et al.*, 2004; Chianucci & Cutini, 2012), their application in understory remains largely unexplored (Kodar *et al.*, 2011; Chianucci *et al.*, 2014b). Visual observations methods such as the Braun-Blanquet scale (1964) provide highly subjective estimates, which severely hamper comparisons among studies; in addition, such methods are unable to provide leaf area index (Macfarlane *et al.*, 2010). Accurate measurements of understory leaf area index are also required for radiative transfer modeling and for calibrating remotely-sensed data (e.g. Kuusk *et al.*, 2004; Peltoniemi *et al.*, 2005; Eriksson *et al.*, 2006; Rautiainen *et al.*, 2011; Pisek *et al.*, 2015).

Recently, Chianucci *et al.* (2014b) proposed a combination of digital photographic methods to obtain rapid, reliable and non destructive estimates of leaf area index of understory. Unfortunately, their measurements were limited to three deciduous species and were not applied at site level; also, the authors were unable to compare overstory and understory leaf (or plant) area index estimates at the time.

In this study, we tested two different, restricted-view angle photographic methods to estimate overstory plant area index and understory leaf area index and their related canopy attributes (crown cover, foliage cover, crown porosity and foliage clumping of the two layers). These methods were applied in beech stands under different management regimes to explore their effectiveness for monitoring the overstory and understory canopy status in differently treated stands.

Materials and methods

Study area

This study was conducted in a mountainous area of central Italy (Alpe di Catenaia; 43°49′N; 11°49′E), which is representative of typical forest systems in the northern and central Apennines. The climate in this area is temperate with warm, dry summers and cold, rainy winters. The mean annual rainfall was 1,164 mm and the mean air temperature was 9.3°.

The study included three permanent research plots established in a previous study in 1972 (Cutini *et al.*, 2015). The plots were located at an altitude of about 1,100 m, with an average slope of 15% and a South-West exposure. All the plots consisted of pure beech coppice stands 67 years old under conversion to high forests either by natural evolution (hereafter TEST) or by two active management options: periodic thinning and seed cutting, as described below. In the periodic thinning plot (hereafter THIN), three low thinnings of medium-heavy intensity were carried out in 1972, 1987 and 2002, which reduced standing basal area by 44%, 38% and 29% respectively, with the last thinning reducing overstory plant area index by 27% (from 5.66 to 4.13 m^2m^{-2}) in 2002 (Cutini *et al.*, 2015). A more intensive option was adopted in the other plot (hereafter SEED), where two low thinnings of medium-heavy intensity (comparable to those carried out in periodic thinning plot) which were done in 1972 and 1987, were followed by an advance seed cutting in 2002, a regeneration cutting that reduced basal area by 56% and overstory plant area index by 79% (from 5.17 to 1.11 m^2m^{-2}) in 2002 (Cutini *et al.*, 2015). A previous study conducted in the research plots revealed that both overstory canopy

Table 1. Main stand attributes of the research plots at two inventories (1972, 2012).

Silvicultural treatment	Stems (n ha-1)	Height (m)	Basal area (n ha-1)	Stems (n ha-1)	Height (m)	Basal area (n ha-1)
SEED	6120	11,2	24,1	108	30,5	19,9
THIN	7407	11,2	27,5	412	26,4	29,8
TEST	7518	11,2	27,4	2046	26,7	48,2

and stand structure were differently modified by the applied silvicultural practices in the long term (Cutini *et al.*, 2015). Compared with unthinned control, the reduction in basal area and overstory plant area index was fully recovered in THIN after ten years from thinning. Conversely, the reduction in basal area and overstory plant area index after seed cutting was not fully recovered in SEED after ten years from seed cutting. This gave us the opportunity to evaluate whether the differences in understory are in agreement with those previously observed at overstory level (Cutini *et al.*, 2015). Table 1 lists the main stand attributes in the research plots.

Overstory and understory canopy attributes

Overstory and understory canopy attributes were estimated using two digital photographic methods, respectively zenith cover photography (Macfarlane *et al.*, 2007; Chianucci & Cutini, 2013) and nadir cover photography (Chianucci *et al.*, 2014b). All images were collected in August 2014 close to sunrise under uniform and calm conditions to prevent wind effect on the leaves. All images were collected using a Nikon D90 DSLR camera (Sendai Nikon Corp., Otawara, Tochigi, Japan) with the aperture set to f/8.0, automatic exposure, ISO 400, automatic white balance, maximum resolution and FINE quality JPEG.

Zenith cover images of overstory were collected on a grid of 9–15 sample points, which were located within each experimental plot. The camera was equipped with AF Nikkor 50 mm f/1.8D lens (mazimum zenith angle range of 0–15°) and pointed upward using a self-leveling tripod. Zenith cover images were analyzed in Winscanopy 2012 (Regent Instruments, Ste-Foy, Quebec, Canada). Foliage cover (FF_O, i.e. the proportion of the ground area covered by the vertical projection of leaves and woody vegetation); crown cover (FC_O, i.e. the proportion of pixels that do not lie in between-crowns gaps, which is equivalent to Nilson's (1999) canopy closure, but also see Jennings *et al.* (1999)), crown porosity (CP_O, i.e. the proportion of sky within crown envelopes) and foliage clumping (Ω_O, i.e., the deviation from random distribution of foliage within the canopy) were estimated from a gap-size distribution approach (Chen & Cihlar, 1995), considering gaps larger than 0.3% of the image area as between-crowns gaps; this gap size threshold was set based on visual image inspection. Plant area index (L_O), including woody materials, was then calculated using an extinction coefficient of 0.85, which was calibrated in a previous study from levelled photographic measurements of leaf inclination angles (Chianucci *et al.*, 2014b):

$$L_O = -\frac{\ln(1 - FF_O)}{0.85 \times \Omega_O}, \text{ where} \tag{1}$$

$$\Omega_O = \frac{(1 - CP_O) \times \ln(1 - FF_O)}{\ln(CP_O) \times FF_O} \text{ and } CP_O = 1 - \frac{FF_O}{FC_O}.$$

Nadir cover images of understory were collected for each plot at the same grid of overstory images; four images were collected and averaged per each grid point for a total of 36–60 images per plot. The camera was equipped with AF Nikkor 18 mm f/2.8 D lens (maximum zenith angle range of 0–50°) and was attached to the top of an extendable 2–10 m. pole via an angled steel bracket such that the camera pointed downward when the pole was held at arm's length with the base of the pole between the operator's feet. Depending on the pole's extensions, images were acquired from a height of 3–4 m above the ground. Understory foliage cover (FF_U) was estimated from two nadir image classification methods, namely LAB2 and Rosin (Macfarlane & Ogden, 2012) as briefly described below.

LAB2 classification method combines pixel chromaticity information (the a^* and b^* coordinates of CIE $L^*a^*b^*$ color model of Mclaren (1976), whose coordinates represent the lightness of the color (L^*), its position between red/magenta and green (a^*) and its position between blue and yellow (b^*)) and a vegetation index (GLA = 2G-R-B/2G+R+B, where G, R, and B represent the green, red and blue channel of the image, respectively) to classify foliage cover (for detail, see Macfarlane & Ogden, 2012); Rosin is an histogram-shape based classification method which detects the point of maximum curvature on a L-shaped curve by fitting a straight line from the maximum to the last non-empty bin of the histogram curve. Both the two nadir image classification methods are largely automated. The greatest disadvantage of the method was that post-analysis quality control is still required: indeed, as previous studies demonstrated (Macfarlane & Ogden, 2012; Chianucci *et al.*, 2014b) LAB2 method should be used for estimates of FF_U > 0.1 while Rosin should be used for estimates of FF_U < 0.1. To avoid subjectivity, when FF_U estimates from Rosin where < 0.1 we adopted Rosin method, and we adopted LAB2 method the way round. The classified images were then processed in Winscanopy for calculation of foliage clumping; gaps larger than 3% of the image area were considered as non random gaps (Chianucci *et al.*, 2014a) and included in the calculation of understory foliage clumping (Ω_U). Leaf area index (L_U) was then calculated (Eq. 1) assuming an overall planophile distribution of understory plants (average extinction coefficient of 0.85 over 0–50° angle range), based on field observations. The contribution of woody elements was considered negligible for downward-looking images.

Additional surveys were conducted in August 2014 to characterize understory diversity. Three 300 m^2 understory plots were randomly established within each plot. The vascular plants were identified and its cover-abundance was estimated using the Braun-Blanquet scale. Subsequently, the cover-abundance values were transformed according to the ordinal scale proposed by Van Maarel (1979) for calculation of diversity indices. Understory diversity was calculated as species richness (SR, i.e., the total number of understory species present in the survey) and Shannon index (H'):

$$H' = -\sum_{i=1}^{s} p_i \, ln(p_i) \qquad (2)$$

where p_i is the proportion of the individuals found in the *i*th species and *s* is the number of species.

Results

The studied stands showed different overstory and understory canopy attributes, as a consequence of the different silvicultural treatments applied (Table 2). Overstory canopy density (i.e. foliage cover, crown cover and plant area index) was significantly lower in SEED compared with the other silvicultural options (Kruskal-Wallis test, $p < 0.01$).

Table 2. Mean and standard error (brackets) of crown cover (FC_0), foliage cover (FF_0), crown porosity (CP_0), foliage clumping (Ω_0) and plant area index (L_0) of forest overstory and leaf area index of forest understory (L_U). Canopy attributes not sharing the same superscript letter are significantly different at the 0.01 level (Kruskal-Wallis).

Plot	FC_0	FF_0	CP_0	Ω_0	L_0	L_U
SEED	0.84 (0.04)[a]	0.78 (0.04)[a]	0.07 (0.01)[a]	0.72 (0.05)[a]	4.57 (0.20)[a]	0.98 (0.07)[a]
THIN	0.97 (0.01)[b]	0.92 (0.01)[b]	0.05 (0.00)[a]	0.90 (0.02)[b]	5.85 (0.11)[b]	0.45 (0.07)[b]
TEST	0.98 (0.00)[b]	0.92 (0.01)[b]	0.06 (0.01)[a]	0.92 (0.02)[b]	5.66 (0.16)[b]	0.44 (0.05)[b]

Overstory foliage clumping decreased (i.e., canopy heterogeneity increased) as overstory leaf area was removed (Figure 1), with SEED exhibiting significantly lower Ω_O values compared with the other silvicultural options (Kruskal-Wallis test, p < 0.01). Conversely, no significant differences in overstory canopy attributes were observed between THIN and TEST plots after ten years from the last thinning (Table 2).

Understory plant area index was negatively correlated with overstory plant area index (Pearson's r_p = 0.67, p < 0.01); as a consequence, L_U increased linearly as L_O was removed (Figure 2), being significantly higher in SEED (Kruskal-Wallis test, p < 0.01). Conversely, no significant differences in L_U were observed between periodic THIN and TEST plots after ten years from the last thinning (Table 2).

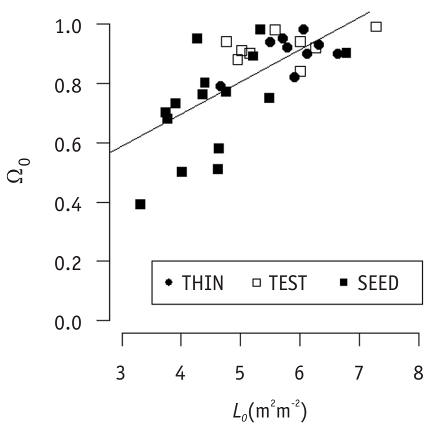

Figure 1. Relationship between foliage clumping index and plant area index of overstory calculated from digital photography. The linear model was $\Omega_0 = 0.11\ L_0 + 0.26$, R^2 = 0.50, RMSE = 0.11.

The differences in canopy attributes observed in the plots were in agreement with biodiversity indices (Table 3); the higher values were observed in the more intensive management option (SEED) while the lower values were observed in the unthinned control (Table 3). In SEED, 6 tree species out of a maximum of 22 plant species were recorded (*Fagus sylvatica* L., *Quercus cerris* L., *Abies alba* Mill., *Prunus avium* L., *Salix caprea* L., *Pyrus pyraster* L. Burgsd.); the average understory height was 1.5 m in that plot. In the other plots, the tree species observed were *F. sylvatica* and *Q. cerris*; the average understory height was 0.4 m in those plots.

Table 3. Mean and standard error (brackets) of species richness (SR) and Shannon index (H') in the studied plots.

Silvicultural treatment	SR	H'
SEED	18.0 (2.0)	1.48 (0.01)
THIN	3.0 (0.6)	0.36 (0.02)
TEST	1.3 (0.3)	0.45 (0.13)

Discussion

We quantified the overstory – understory relationship in terms of leaf (or plant) area index and its related canopy attributes. Importantly, a significant relationship between L_O and L_U was observed in the stud-

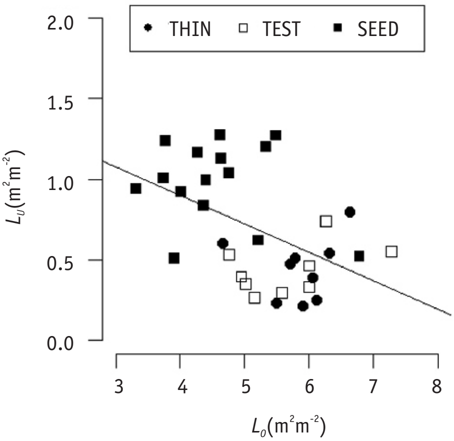

Figure 2. Relationship between L_U and L_O calculated from digital photography. The linear model was $L_U = -0.18\ L_O + 1.60$, $R^2 = 0.45$, RMSE = 0.30.

ied plots; the observed relationship ($L_U = -0.18\ L_O + 1.60$) was comparable with that obtained by Kodar *et al.* (2011) ($L_U = -0.21\ L_O + 1.61$) in Järvselja (Estonia). Consistently with L_O removal, L_U was significantly higher in SEED plot, compared with the other surveyed management options. Conversely, no differences in both L_O and L_U were observed between THIN and TEST plots. Some studies have observed a response of understory to thinning (e.g. Borg & Stoneman 1991; Lane & Mackay, 2001), but these studies have not described such response in a quantitative manner. In addition, overstory and understory relationships have more frequently described as cover rather than plant area index of the two layers (Macfarlane *et al.*, 2010). At another level, most of previous studies have focused on early response of understory to thinning (e.g. Decocq *et al.*, 2004; Dodson *et al.*, 2008); our observed overstory–understory significant relationship was observed after ten years from thinning, demonstrating the change associated to the silvicultural practices were not ephemeral, in agreement with previous reports (Cutini *et al.*, 2015; Chianucci *et al.*, 2015). Based on the results, we conclude that the proposed photographic methods are effective for monitoring overstory and understory canopy status in managed stands. Use of digital photography is desirable as the method is fast, cost-effective and not destructive (Lang *et al.*, 2013), being therefore highly suitable for large scale, objective and broadly comparable measurements of understory and overstory canopy interactions, phenological studies, monitoring and research programs.

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