A simple Light Meter as a Device for studying the Influence of Seasonal Changes of Light Conditions on the Phenology of Herbaceous Undergrowth Species in a Fertile Beach Forest

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Abstract

The purpose of the study was to test a simple light meter (luxe meter) as a tool for determining light conditions in the fertile beach forest understory, as well as, evaluating its usefulness in understanding the determinants of changes in the phenology of fertile beach forest undergrowth species. Field research was conducted during the period from 10 March to 10 November 2014. A permanent plot (100 m^2) was located in the fertile beech forest *Dentario glandulosae-Fagetum*, the Świętokrzyskie Mountains (southern Poland). Phytosociological relevés were done (for seven months of the growing season; every four weeks on average) on the permanent plot using the Braun-Blanquet method. In addition, phenological phases of herbaceous species of undergrowth which occurred in every relevé were noted.

In the centre of the permanent plot and in the nearby glade measurements of illuminance, E, were performed once a week, using a hand-held light meter. The measured illuminance (in lux) values were converted into photosynthetic photon flux density PPFD (in $mmol·m^{-2}·s^{-1}$) and irradiance I (in $W·m^{-2}$). The changes of the absolute values of the indices of light conditions and the overstory light transmission (in %) were analyzed. The illuminance values measured using a simple light meter accurately reflected changes in fertile beech forest understory light conditions depending on vegetation variability, cloudiness and wind speed. A significant negative correlation was found: $r_s = -0.93$ at $p = 0.003$ ($t = -5.51$) between the percentage coverage of tree layer (based on the Braun-Blanquet scale) and the overstory light transmission (obtained from the illuminance measurements). Statistically significant relations between the percentage coverage of tree layer and the number and percentage coverage of geophytes and hemicryptophytes in a particular phenophase were also found.

Keywords: fertile beech forest, luxe meter, permanent plot, percentage coverage, Poland.

Introduction

Light is a factor limiting the presence of plants, where its intensity is so low that it reduces the intensity of photosynthesis, i.e. below the light saturation point. According to Daniels (1956) this refers to the energy of light of less than 50 000 $erg·cm^{-2}·s^{-1}$, i.e. approx. 50 $W·m^{-2}$.

Particular attention is paid to the intensity of photosynthetic active radiation (PAR), in the range of 400-700 nm, whose measure is the photosynthetic photon flux density (PPFD), expressed in $mmol·m^{-2}·s^{-1}$. Quantum sensors are used in direct PPFD measurements (e.g. Comeau 2000, Lieffers et al. 1999).

The intensity of light is strongly limited in the forest understory. As a rule, the relative values of PPFD, i.e. the transmittance of PAR by the stand canopy (% PPFD), are determined in the forest understory. In the evaluation of the PAR transmittance by the stand canopy, indirect methods are also often used such as: hemispherical photography or evaluation of the Diffuse-Non-Interceptance (DIFN), a measure of canopy openness, using the LAI-2000 analyzer (e.g. Engelbrecht and Herz 2001, Machado and Reich 1999).

In the past, simple light meters measuring the illuminance (E) in lux (lx) were also used in geobotanical research (e.g. Klein 1977; Roussel 1953). Some authors, however, did not recommend using them in such studies (e.g. Anderson 1964a, Jennings et al. 1999). They emphasize that the illuminance, which is measured by simple light meters, is a photometric quantity defined with respect to the human eye sensitivity to electromagnetic radiation. Therefore it is not the most appropriate device for geobotanical studies, although its usage was evaluated as acceptable (Anderson 1964a). In fact, spectral ranges of the illuminance and the PAR are nearly identical. Moreover, a few authors (e.g. Jennings et al. 1999) claim there is no method to convert illuminance measures into measures relevant to plant physiological processes without detailed knowledge of the spectral composition of the light. It is not entirely true, as a simplified method to calculate PPFD from illuminance using conversion factors was developed by Thimijan and Heins (1983) for various light sources. Regardless of the criticism mentioned above simple light meters were used occasionally in geobotanical studies (e.g. Zang et al. 2005; Zielińska et al. 2016). In fact, they are readily available, inexpensive and easy-to-use instruments, which is an advantage in the field research. Thus, it seems that it is worth using simple light meters as an alternative to more advanced measurement systems.

The main purposes of this study are to answer two questions: whether a simple light meter allows for quick and reliable identification of light conditions in the fertile beech forest understory and can help interpret seasonal changes in the percentage coverage of tree layer and the phenology of fertile beech forests undergrowth species?

Materials and Methods

Study area

The study area is located on the Święty Krzyż (‘Holy Cross’) hill in Łysogóry Range in the Świętokrzyskie Mountains (SE Poland). The Święty Krzyż hill reaches 594 m a.s.l.

The annual average air temperature on the Święty Krzyż hill is 5.7°C. The length of the thermal growing season, calculated according to Gumiński method (as cited in Kępińska-Kasprzak and Mager 2015) is 185 days. The annual precipitation total is 807 mm. The total annual sunshine duration in the Święty Krzyż hill is 1580 hours. In the summer months, the sunshine duration (225 hours in July) and the relative sunshine duration (63% in August) are the greatest (Olszewski et al. 2000).

The study area is located within the Świętokrzyski National Park.

Data set

Our research was conducted in 2014 from 10 March to 10 November using the permanent plot method (Faliński 2001). The permanent plot was located in a beech forest on the northern slope of the Święty Krzyż hill at 505 m a.s.l. (geographical coordinates: 50°51’ 43.32”N, 21°03’22.84”E). The size of the permanent plot was 100 m^2 (it was a square 10 m × 10 m).

Systematic phytosociological relevés were done on the permanent plot from March to September (every four weeks on average) using the Braun-Blanquet method (Braun-Blanquet 1964, Dzwonko 2007). All phytosociological relevés were done within the borders of permanent plot. Moreover, the size of permanent plot is adequate to the size of every relevé (100 m^2) which was done in a given part of a growing season. In total seven relevés were done in the permanent plot. In addition, phenological phases of herbaceous forest undergrowth species which occurred in every relevé were noted.

Illuminance (E in SI system) measurements were conducted from March to November 2014. The illuminance in the forest was measured once a week, 1-2 hours before noon, in the center of the permanent plot (approx. 1.8 m AGL), using hand-held light meter (L-50, SONOPAN Sp. z o.o., Białystok, Poland). During the measurement, the light meter sensor was aligned directly upwards, detecting the amount of light reaching the sensor from the entire sky hemisphere.

A similar methodology of measurements was used in the adjacent Bielnik glade which represents the conditions of open field light conditions. Both locations (forest-glade) are within a distance of 50 m, so the time between light measurements did not exceed 5 minutes, which is in line with Comeau (2000) recommendations. The measurements were conducted both in overcast days and in less cloudy days. The amount of cloud cover by the low-level and mid-level clouds – N (in oktas) was estimated by visual observations on the Bielnik glade.

We used wide-angle digital photographs of tree canopies for the additional testing the usefulness of the simple light meter in the estimation of understory light conditions. Wide-angle photographs has already been used in such studies (e.g. Engelbrecht and Herz 2001, Korhonen et al. 2006). Photographs were taken with a digital camera Olympus C-720 Ultra Zoom (Olympus Optical CO., Ltd., Tokyo, Japan) in the center of the studied permanent plot. The camera settings were the same for all pictures with maximal wide angle (f = 6.4 mm, which is an equivalent to f = 40 mm on a regular 35-mm camera). In total, 4 photographs were taken. The first one was taken on 10 March, before the foliage of tree canopies started to develop, the last one on 22 August when the tree foliage was fully developed. Other two photographs were taken on 22 April and 12 May and they recorded subsequent stages of the foliage of tree canopies development.

Data analysis

The measured illuminance values, E (in lux), were converted into PPFD (in mmol·m^{-2}·s^{-1}) and irradiance, I (in W·m^{-2}), using conversion factors. In order to calculate PPFD, the illuminance values were divided by the computational factor which, for the sunlight, is 54 (Thimijan and Heins 1983). Then to calculate the irradiance (in $W \cdot m^{-2}$), the PPFD value (in $\mu mol \cdot m^{-2} \cdot s^{-1}$) was multiplied by the conversion factor which for the solar radiation amounted to 0.51 (Runkle 2006).

Both the absolute values of E, PPFD and I as well as the canopy light transmission, i.e. the ratio (in %) of PPFD (as well as E and I) under tree crowns to open field values, were taken into account in the analysis of understory light conditions. By analyzing the changes in the canopy light transmission and the absolute values of PPFD (and E and I), their arithmetic means were compared between periods with developed foliage and those without leaves (or with small foliage). In the period with developed foliage, also the light condition differences between cloudy days ($N \geq 6$ in oktas) and days with less cloudiness were studied. The statistical significance of the differences in the calculated means was assessed using the non-parametric Mann-Whitney *U*-test.

Wide-angle photographs were analyzed with the use of the Forest Crowns Assessment Software (Winn et al. 2016). It allowed estimating a percentage of skylight visible through the 2-dimensional forest canopy from a point on the ground, which is called the transparency of forest canopy. Correlation was calculated between the transparency of forest canopy estimated from wide-angle photographs and the canopy light transmission estimated with the use of the simple light meter.

The obtained phytosociological relevés were used to compile the phytosociological table according to generally accepted methods (Dzwonko 2007), which allowed determining type of the community. The floristic composition of the relevés and degrees of abundance-coverage determined in relevés according to the Braun-Blanquet scale have been the basis for the subsequent analyses. The percentage cover classes assigned to the Braun-Blanquet scale are as follows: + < 5%, 1 = 5%, 2 = 5–25%, 3 = 25–50%, 4 = 50–75%, 5 = 75–100% (Braun-Blanquet 1964). Correlations were made to illustrate the relationship between the percentage coverage of trees layer changing during the growing season and the selected variables: 1) the number of species from certain ecological groups of herbaceous undergrowth (Raunkiaer's life forms: chamaephyte, hemicryptophyte, geophyte, therophyte, according to Zarzycki et al. 2002), 2) their phenological phases: vegetative, flower buds, flowering, immature fruits, mature fruits and seeds spreading, dormancy (Szafer 1922, Baddour and Kontongomde 2009) and 3) the level of illuminance measured using a simple light meter.

The adopted measure of correlation was Spearman's rank correlation coefficient (r_s), because the data did not met an assumption of normality.

All results of the conducted analyses were considered as statistically significant at $p \leq 0.05$. The analyses were performed using the Statistica 6.1 software package (StatSoft 2003).

Nomenclature of the species was adopted according to the Plant List (www.theplantlist.org), syntaxonomical nomenclature according to Matuszkiewicz (2014).

Results

Structure of the community and phenological phases of species in a relationship with the seasonal variability of the percentage coverage in the tree layer

The community, where the permanent plot is located, represents the fertile Carpathian beech forest *Dentario glandulosae-Fagetum* according to an analysis of phytosociological relevés (Table 1). This community is multilayered and characterized by a large floristic richness (as opposed to acid beech forest *Luzulo-Fagetum,* a community which is species-poor; Matuszkiewicz 2014). In total, 37 species of vascular plants were found in the relevés in the studied community, including 29 herbaceous species and 8 trees and bushes. The basis for this association is the species characteristic of the *Querco-Fagetea* class individual syntaxones (Table 1).

The tree layer (a1 and a2) is dominated by *Fagus sylvatica*, which reached the 5th degree of cover in the high tree (a1) layer in July and have sustained it until September (Table 1). It is accompanied by *Carpinus betulus*, *Acer pseudoplatanus* and *Abies alba*, which are the regular component of most forest phytocoenoses in the Łysa Góra hill region. The most common in the upper bush layer (b1) is *C. betulus*, while in the lower bush layer (b2) are *A. pseudoplatanus* and *Sambucus nigra*.

The floristic richness of the studied community is influenced mainly by herbaceous species which account for almost 80% of all species found on the permanent plot throughout the growing season. The following was stated taking into account the life forms of those species: 18 hemicryptophytes, 8 geophytes, 2 chamaephytes and 1 therophyte (Table 1). Thus, the presence of geophytes and hemicryptophytes is a major factor in the structure of this community. Owing to those two groups of plants in *Dentario glandulosae-Fagetum*, a distinct early spring aspect, in which the qualitative and quantitative dominance of geophytes in the undergrowth was found, and the summer aspect dominated by hemicryptophytes (Table 1, Figure 1) can be observed. Those changes are affected *inter alia* by the access of light into the undergrowth, whose intensity changed during the growing season, depending on the leaves development. The level of cover of the tree layer (a1 + a2) on the permanent plot was within wide limits: from 30% (early spring) to 110% (summer).

Analyzing the dependence of the number of species representing the individual life forms on the per-

Table 1. Floristic composition of the *Dentario glandulosae-Fagetum,* a community found within the boundaries of the permanent plot; to show the percentage cover of the species the Braun-Blanquet scale is used (+ < 5%, 1 = 5%, 2 = 5%–25%, 3 = 25%–50%, 4 = 50%–75%, 5 = 75%–100%); Ch stands for species characteristic for respective syntaxons: All. stands for alliance, Ass. stands for association, Cl. stands for class, O. stands for order (Braun-Blanquet 1964); the following additional data were added for herbaceous plants: Lf denotes life forms (C stands for chamaephyte, H stands for hemicryptophyte, G stands for geophyte, T stands for therophyte, according to Zarzycki et al. 2002) and development phases observed in the permanent plot: V stands for vegetative, B stands for flower buds, E stands for flowering, F stands for of immature fruits, S stands for mature fruits and seeds spreading, and D stands for dormancy (Szafer 1922, Baddour and Kontongomde 2009)

No. of relevé		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Date (d/m/y)		10.3. 2014	22.4. 2014	12.5. 2014	09.6. 2014	11.7. 2014	18.8. 2014	25.9. 2014
Area of relevé	[m^2]	100	100	100	100	100	100	100
Exposure		N	N	N	N	N	N	N
Slope	[°]	5	5	5	5	5	5	5
Coverage of tree layer a1	[%]	25	35	55	75	90	90	90
Coverage of tree layer a2	[%]	5	7	10	15	20	20	20
Coverage of shrub layer b1	[%]	5	5	10	10	10	10	10
Coverage of shrub layer b2	[%]	10	15	25	30	30	30	25
Coverage of herb layer c	[%]	20	75	90	70	60	50	35
No. of species in relevé		16	33	37	34	33	31	28
	layer							
Trees and shrubs:								
ChAll. Fagion								
Fagus sylvatica	a1	2	3	3	4	5	5	5
Fagus sylvatica	a2	+	+	2	2	2	2	2
Fagus sylvatica	b2	+	+	1	1	1	1	1
Fagus sylvatica	c	.	1	1	+	+	+	+
ChAll. Carpinion								
Carpinus betulus	a2	+	+	1	2	2	2	2
Carpinus betulus	b1	+	1	2	2	2	2	2
Carpinus betulus	b2	+	+	+	+	+	+	+
Tilia cordata	c	.	+	+	+	+	+	+
ChAll. Tilio platyphylli-Acerion pseudoplatani								
Acer pseudoplatanus	a1	+	+	+	2	2	2	2
Acer pseudoplatanus	b2	+	1	2	2	2	2	2
Acer pseudoplatanus	c	.	1	1	1	+	+	+
ChCl.Querco-Fagetea								
Acer platanoides	b2	+	+	+	1	+	+	+
Accompanying species:								
Abies alba	a1	+	+	+	+	+	+	+
Abies alba	b2	1	1	1	1	1	1	1
Abies alba	c	+	+	+	+	+	+	+
Sambucus nigra	b2	1	1	2	2	2	2	2
Sorbus aucuparia	c	.	+	+	+	+	+	+

Table 1. (continued).

No. of relevé			**1**	**2**	**3**	**4**	**5**	**6**	**7**
	layer	**Lf**							
Herbs:									
ChAss. Dentario glandulosae-Fagetum									
Cardamine glandulifera	c	G	1^{B}	$2^{E/F}$	1^{S}	1^{D}	$+^{D}$	$+^{D}$	.
ChAss. Ficario-Ulmetum									
Ficaria verna	c	G	1^{V}	3^{E}	2^{S}	1^{D}	.	.	.
ChAll. Alno-Ulmion									
Stellaria nemorum	c	H	$+^{V}$	$+^{V}$	1^{E}	1^{F}	1^{S}	1^{V}	$+^{V}$
Gagea lutea	c	G	$+^{V/B}$	$+^{E}$	$+^{F/S}$	.	.	.	.
ChO. Fagetalia									
Lamium galeobdolon	c	C	$+^{V}$	$+^{B}$	1^{E}	1^{F}	1^{S}	2^{V}	1^{V}
Milium effusum	c	H	$+^{V}$	$+^{V}$	$+^{E}$	$+^{F}$	$+^{S}$	1^{V}	$+^{V}$
Impatiens noli-tangere	c	T	.	1^{V}	2^{V}	$3^{V/B}$	$3^{E/F}$	$2^{S/D}$	1^{D}
Stachys sylvatica	c	H	.	1^{V}	2^{V}	2^{B}	2^{E}	2^{S}	2^{V}
Veronica montana	c	C	.	$+^{V/B}$	$1^{E/F}$	$1^{F/S}$	1^{V}	1^{V}	.
Dryopteris filix-mas	c	H	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$
Galium odoratum	c	H	.	$+^{V/B}$	$+^{E/F}$	$+^{S}$	$+^{V}$	$+^{V}$	$+^{V}$
Pulmonaria obscura	c	H	.	$+^{B}$	$+^{E/F}$	$+^{S}$	$+^{V}$	$+^{V}$	$+^{V/D}$
Ranunculus lanuginosus	c	H	.	$+^{V/B}$	$+^{E}$	$+^{F/S}$	$+^{V}$	$+^{V}$	$+^{V}$
Viola reichenbachiana	c	H	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$
Corydalis solida	c	G	$+^{V}$	$+^{E/F}$	$+^{S/D}$	.	.	.	.
ChCl. Querco-Fagetea									
Aegopodium podagraria	c	H	.	$+^{V}$	$+^{V}$	1^{V}	$+^{V}$	2^{V}	2^{V}
Anemone nemorosa	c	G	$+^{V}$	$2^{B/E}$	$+^{E/F}$	$+^{V/D}$	$+^{V/D}$	.	.
Accompanying species:									
Galanthus nivalis	c	G	$2^{B/E}$	$2^{E/F}$	$1^{S/D}$	.	.	.	.
Urtica dioica	c	H	$+^{V}$	$+^{V}$	$+^{V/B}$	$+^{E/F}$	$+^{S}$	$+^{V}$	$+^{V}$
Athyrium filix-femina	c	H	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$
Chaerophyllum aromaticum	c	H	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V/D}$
Hieracium murorum	c	H	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$
Lamium maculatum	c	H	.	$+^{V}$	$+^{E}$	$+^{F/S}$	$+^{V}$	$+^{V}$	$+^{V}$
Oxalis acetosella	c	G	.	$+^{B}$	$+^{E/F}$	$+^{S}$	$+^{V}$	$+^{V}$	$+^{V/D}$
Maianthemum bifolium	c	G	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	.	.
Dryopteris dilatata	c	H	.	.	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$	$+^{V}$
Mycelis muralis	c	H	.	.	$+^{V/B}$	$+^{E}$	$+^{F}$	$+^{S}$	$+^{V}$
Senecio nemorensis	c	H	.	.	$+^{V}$	$+^{B}$	$+^{E}$	$+^{E/F}$	$+^{S}$
Moehringia trinervia	c	H	.	.	$+^{V/B}$	$+^{E}$	$+^{F}$	$+^{S}$	$+^{D}$

centage coverage of tree layer, it was found that the following two groups of plants reacted to the changes of foliage: geophytes and hemicryptophytes (Figure 1). For geophytes, a very high negative correlation was found: $r_s = -0.84$ at probability level $p = 0.018$ ($t = -3.48$). Thus, the greater the leaf shade induced by leaf development the smaller the number of geophytes were found in the phytosociological relevés which were done on the permanent plot. On the other hand, the number of hemicryptophytes increased with increasing area shading: positive correlation $r_s = 0.83$ at $p = 0.02$ ($t = 3.35$).

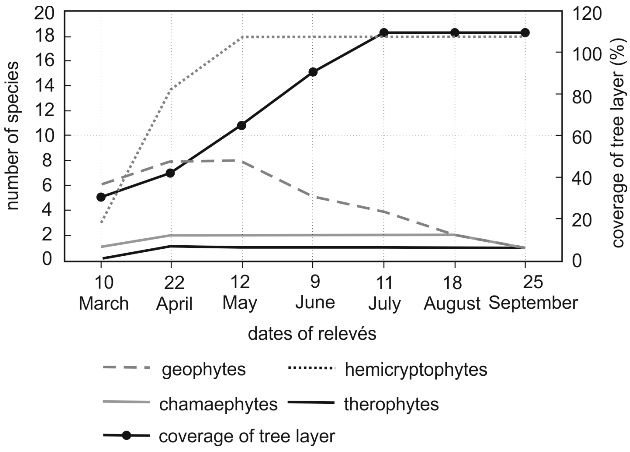

Figure 1. Relationships between tree foliage development and a number of fertile beech forests undergrowth species representing a given life form in consecutive phytosociological relevés

For geophytes, the existence of particular phenophases is also dependent on the degree of the tree cover (Figure 2). For the generative phase (flower buds, flowering, fruiting, seed spreading), a high negative correlation was found: $r_s = -0.87$ at $p = 0.01$ ($t = -4.04$) with the degree of coverage of tree layer – the higher the percentage coverage the less geophytes in the generative phase were found in the permanent plot (Figure 2). The beginning of the generative phase (presence of flower buds) begins at about 30% of the area coverage by the tree layer (a1 + a2). All species finish blooming before the trees cover 40% of the relevé area, and most of them fruit at approx. 60% coverage. Geophytes finish the generative phase before the trees reach the maximum degree % of coverage (Table 1).

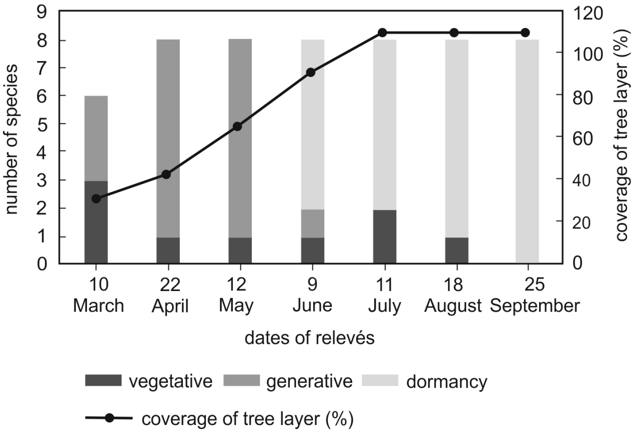

Figure 2. Relationships between tree foliage development and a number of geophytes representing a different development phase in consecutive phytosociological relevés

Conversely it is presented the revealed correlation for the dormancy phase: a positive correlation was found, $r_s = 0.89$ at $p = 0.007$ ($t = 4.44$). The higher the percentage coverage of tree layer the more geophytes went into the dormancy phase (Figure 2). For the vegetative phase, the correlation is not statistically significant.

Light estimates made with the use of a simple light meter and tree canopy photographs

The illuminance (E) in the fertile beech forest understory varied over a wide range from 0.6 to 59.4 klx during the period from 10 March to 10 November 2014 when photometric measurements were conducted. This period generally fits in with the thermal growing season in 2014 which was very long and lasted 235 days. Those values correspond to the PPFD in the range from 11.1 to 1100.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and the irradiance (I) in the range from 5.7 to 561.0 $W \cdot m^{-2}$.

The light transmittance of crowns varied from 1.4% to 65.3% over the research period (Figure 3B). It was characterized by a clear seasonal variability (Figure 4A) which was associated with the development and falling of leaves of deciduous trees and bushes in the *Dentario glandulosae-Fagetum* (Table 1). The highest values of illuminance in the understory occurred in the period before the trees leaves development (in the year of 2014 until the last decade of April) and after their fall (since the last decade of October). During this period, the canopy light transmission was 28-65% (Figure 4A). The canopy light transmission was being reduced gradually in May during the leaf development (Table 1; Figure 4A). The canopy light transmission was lower than 10% in the period since mid-May till early October and lower than 5% in July and August (Figure 4A). In general, the

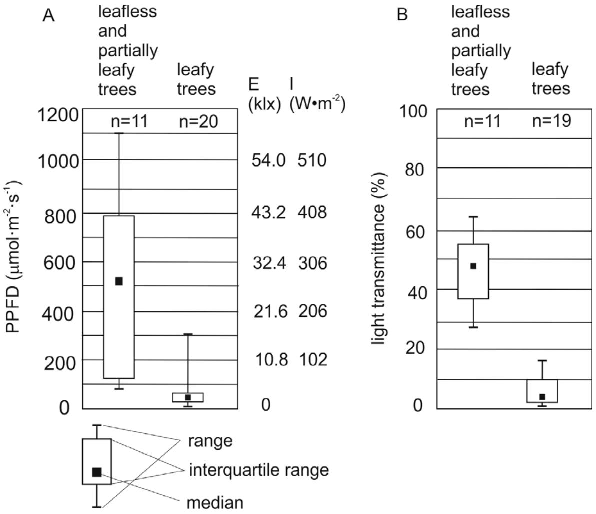

Figure 3. Variability of light conditions in the understory of the studied *Dentario glandulosae-Fagetum* community depending on the tree foliage development: A. PPFD, E and I values; B. light transmittance

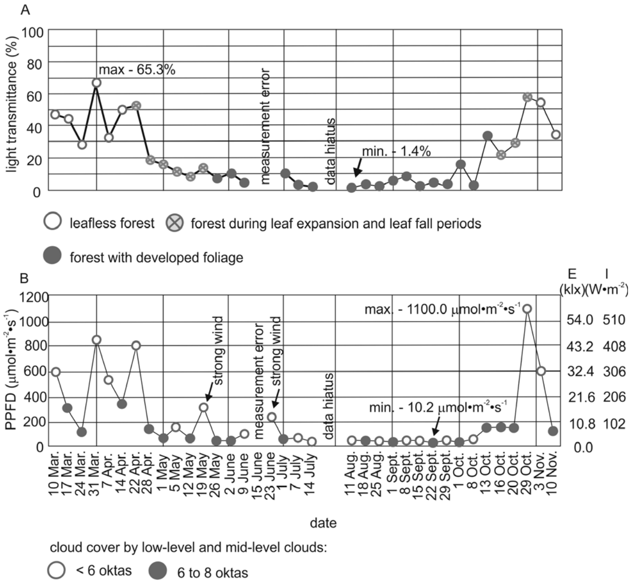

Figure 4. Light conditions variability in the understory of the studied *Dentario glandulosae-Fagetum* community during a period between 10 March - 10 November 2014; A. light transmittance; B. PPFD, E and I values

light transmission of the canopy of the *Dentario glandulosae-Fagetum* was more than 7 times lower in the period with developed foliage than when the trees were deprived of leaves (Figure 3B). This difference is statistically significant in the light of the Mann-Whitney *U*-test value, ($U = 0.0$; $p < 0.001$).

Similar variability is seen with respect to absolute values of the light intensity (E), photosynthetic photon undergrowth density (PPFD), and solar radiation intensity (I). During the measurements performed at the time, when the trees were deprived of leaves, E on the floor of the forest amounted to an average of 27.0 klx, PPFD = 499.7 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and I = 254.8 $W \cdot m^{-2}$. In the period when the trees were leafy E in the forest floor amounted to an average of 3.6 klx, PPFD = 66.5 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and I = 33.9 $W \cdot m^{-2}$ (Figure 3A). Those differences are also statistically significant ($U = 10.0$ at $p < 0.001$).

Against the background of the generally low E values in the period from mid-May to the end of September, its values stand out on May 19 and June 23, 2014 (Figure 4B). On June 23, winds of force of up to 6° on the Beaufort scale blew, and on May 19, winds of force of 4° on the Beaufort scale blew. This facilitated the penetration of the sunlight into the understory. As a result, on June 23, E in the fertile beech forest understory amounted to 13.3 klx (PPDF = 246.3 $\mu mol \cdot m^{-2} \cdot s^{-1}$, I = 125.6, $W \cdot m^{-2}$). On May 19, in the forest understory it amounted to 16.9 klx (PPDF = 313.9 $\mu mol \cdot m^{-2} \cdot s^{-1}$, I = 160.1 $W \cdot m^{-2}$).

In addition to the coverage in the layer of trees and bushes, the amount of light under the trees crowns is also affected by the cloudiness, however it is less affected (Figure 4B). PPFD (as well as E and I) values under tree crowns were 2.7 times lower on cloudy days than on less cloudy days (Table 2). This difference is statistically significant ($U = 11.0$ at $p = 0.007$). The opposite regularity was evident in the case of the canopy light transmission. The canopy light transmission during the period with developed foliage increased in cloudy days (on average by 1.5 times) compared with less cloudy days (Table 2). However, this difference is not statistically significant.

Forest crowns transparency estimated with the use of canopy photographs varied from 19.1 to 75.4%. It decreased following the foliage development in a similar manner as the light transmittance of crowns estimated with use of the simple light meter. The correlation (r_s = 0.80) between these two sets of measures of light conditions in the fertile beech forest understory is not statistically significant yet.

Table 2. Light conditions depending on cloud cover in the fertile beech forest understory during the period with developed tree foliage

light indices	cloud cover by low-level and mid-level clouds	
	<6/8	≥ 6/8
PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	56.6	20.9
I ($W \cdot m^{-2}$)	28.9	10.6
E (klx)	3.1	1.1
light transmittance (%)	3.9	7.2

Light intensity and seasonal changes in the community

In the *Dentario glandulosae-Fagetum* community both absolute values of PPFD and E and I as well as canopy light transmission (in %) were dependent on the development of foliage. The canopy light transmission decreased in the growing season in 2014 from 30-65% in March and April, when the trees were not yet leafy to <5% in August, with developed foliage.

By analyzing the calculated values of the solar irradiance (I) in the fertile beech forest understory, it can be stated that in the center of the fixed permanent plot I ≤ 50 $W \cdot m^{2}$ values occurred in 75% of observations. Moreover, during the period when the foliage of tree canopies was already developed (Table 1; Figure 4B), only 2 times the illuminance (E) was recorded, which corresponded to a irradiance of more than 50 $W \cdot m^{-2}$. Thus, the changes in the light conditions also affected the changes in the phenological phases of the forest undergrowth species as well as their degrees of coverage.

On March 10 (Table 1) the high tree layer (a1) covered 25% of the permanent plot area (2nd degree of Braun-Blanquet scale). On that day PPFD amounted to 593.6 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (E = 32.2 klx, I = 302.7 $W \cdot m^{-2}$), which accounted for 47.0% of PPFD, E and I in the glade. The transparency of forest canopy estimated on a photograph was 75.4% then. At that time 6 geophytes were present in the undergrowth (Figure 1). Only two of them – *Galanthus nivalis* and *Cardamine glandulifera* – were in the generative phase. The fully flowering *G. nivalis* had the highest degree of coverage (approx. 25%).

On April 22 (Table 1), when the tree layer coverage reached the 3rd degree of Braun-Blanquet scale, PPDF under tree crowns amounted to 798.1 $\mu mol \cdot m^{-2} \cdot s^{-1}$, E amounted to 43.1 klx and I amounted to 407.0 $W \cdot m^{-2}$, which accounted for 52.5% of the light intensity in the glade. The transparency of forest canopy estimated on a photograph was 39.1% then. At that time, the flowering *Ficaria verna* herb dominated the herbaceous undergrowth, which occupied approx. 40% of the area, and *G. nivalis* was passing through the immature fruit phase. Geophytes reached a maximum of 8 species (Figure 1).

On May 12, the tree layer reached the 4th degree of the Braun-Blanquet scale (Table 1). The measured illuminance under trees crowns was reduced to 3.1 klx, which corresponds to PPFD = 57.4. $\mu mol \cdot m^{-2} \cdot s^{-1}$ and I = 29.3 $W \cdot m^{-2}$. The canopy light transmission was 8.4%. The transparency of forest canopy estimated on a photograph was 24.2% then. Then, in the herbaceous undergrowth, it was observed that quantitative participation of geophytes began to diminish considerably in favour of hemicryptophytes: both life forms of plants coexisted to achieve similar levels of coverage (Figure 1). However, the hemicryptophytes were at the beginning of their vegetative phases (e.g. *Stachys sylvatica*), whereas the photophilous geophytes reached their full development (flowering, fruiting and seed spreading).

On June 9, 2014 (Table 1) the coverage at tree layer (a1 + a2) was 90% (5th of Braun-Blanquet scale). Under the tree crowns PPFD amounted to 92.8 $\mu mol \cdot m^{-2} \cdot s^{-1}$, E = 5.0 klx and I = 47.3 $W \cdot m^{-2}$. Those values accounted for 4.4% of PPFD, E, and I on the glade. At that time, geophytes significantly reduced their degrees of abundance-coverage, and most of them went into the dormancy phase. *Impatiens noli-tangere* (a therophyte) dominated the phytosociological relevé, covering approx. 40% of the permanent plot.

In July, trees on the permanent plot reached the maximum percentage of coverage, which also persisted in August and September (Table 1). At that time the structure of the community and its floristic composition fully corresponded to the summer aspect of *Dentario glandulosae-Fagetum*.

On August 18, with 90% coverage of the high tree layer (a1), PPFD only amounted to 28.0 $mol \cdot \mu m^{-2} \cdot s^{-1}$, E =1.5 klx, and I = 14.3 $W \cdot m^{-2}$. This represents 3.4% of the value of the light conditions indicators analyzed in the glade. The transparency of forest canopy estimated on a photograph was 19.1% then. In the community undergrowth the highest degrees of abundance-coverage were achieved by *Aegopodium podagraria*, *Lamium galeobdolon*, *Impatiens noli-tangere*, *Stachys sylvatica*. At this time, the first two species were in the vegetative phase, two subsequent ones were at the final stage of the seed spreading (Table 1).

In September, the community started its passage into the dormancy phase (Table 1).

The calculated values of the canopy light transmission were strongly correlated with the visually assessed percentage coverage of tree layer (based on Braun-Blanquet scale) in the taken phytosociological relevés. The correlation is negative $r_s = -0.93$ at probability level of $p = 0.003$ ($t = -5.51$). So the greater was the percentage coverage of tree layer the less light came into the fertile beech forest understory.

Discussion and Conclusions

The values of illuminance measurements made with a simple light meter appear to accurately reflect changes in the forest understory light conditions, taking into account both the seasonal variability of vegetation and the aperiodic variation of cloud cover. The question remains as to how much of the measured values of the canopy light transmission (in %) are comparable to the values obtained with the help of more advanced light meters directly measuring the PPFD.

In the *Tilio-Carpinetum* community located in the Niepołomice Forest in southern Poland, the intensity of PAR under tree crowns accounted for 10% of the measured values in the open field and only 3% in the forest undergrowth layer (Klein 1977). In the Karkonosze Mountains (SW Poland), at the floor of the beech stand forest, where the coverage of trees layer was 90%, the relative amount of PPFD was 10% (Robakowski et al. 2000). Even lower values of PAR transmittance through the crowns of trees are given by van Eimern (1987) for beech forests growing on Göttinger Wald (Lower Saxony, Germany). In the months of July-September 1984 only 1.5-2.0% of the PAR recorded in the open field reached the forest floor. Canham and Burbank (1994) investigating the light conditions in the New England forests understories found that in the tree stand dominated by *Fagus grandifolia,* on average only 2% of the PAR observed in the open field was reaching the forest floor. In our study, in permanent plot with 95% tree coverage, the light penetration through the canopy to the forest floor was 3-5%. Thus, the assessment of the canopy light transmission obtained through the measurement with a simple light meter and quantum/PAR sensors allow obtaining similar results.

Moreover, a strong positive correlation ($r_s = 0.80$) was obtained between estimates of understory light conditions made with use of the simple light meter and wide-angle photographs. The correlation was not statistically significant yet, probably due to limited number of available photographs.

Some researchers report (e.g. Miller 1959, Słomka and Dunikowski 1959, Urban et al. 2007) that on cloudy days the light transmittance of the canopy (%) is greater than on the sunny days. This is in line with the illuminance assessment in the fertile beech forest undergrowth within our permanent plot. However, not all studies confirm the above-described pattern (Comeau et al. 1998). This relationship was, in the permanent plot, related only to the canopy light transmission, i.e. the relative measure of light conditions. The absolute values of PPFD, I, and E under tree crowns were more than 2 times greater on sunny days than on cloudy days (Figure 3).

This is a proof that, in assessing the light conditions in the forest understory, one cannot stop merely on defining the canopy light transmission. The absolute values of PPFD (as well as I and E) should also be determined. Those are the absolute values that determine whether a species of forest undergrowth may develop under given conditions. In addition, as described by Anderson (1964b), analysis of only relative light intensity values may result in underestimation of the light reaching the forest floor at the initial stage of a tree foliage development. The canopy light transmission starts to decrease then. However the increase in the angular height of the Sun at noon causes an increase in the intensity of solar radiation at the same time, for some time visible also in the forest floor.

The low values of solar irradiance (I) calculated from the measurement with luxe meter suggest that in the undergrowth of the *Dentario glandulosae-Fagetum* the light factor should influence the forest undergrowth species phenology. This fact is confirmed by phytosociological relevés, which were done during the growing season. Changes in the light intensity are correlated both with the changes of percentage coverage of tree layer in the Braun-Blanquet scale and phenological changes of geophytes and hemicryptophytes dominating the undergrowth herbaceous species (Table 1; Figures 1 and 2). Similar temporal coincidence of flowering of forest undergrowth vegetation and changes of available light is described, among others, in the forest areas of Illinois (USA), in the tree stand dominated by *Acer saccharum* and *Quercus rubra* (Schemske et al. 1978). There, the flowering time of early spring herbaceous plants was from mid-March to early May. During this period the canopy light transmission was initially high (> 45%), and then gradually decreased to approx. 10%. In our permanent plot, in May, when the light transmission of the tree canopy began to decline, most geophytes were already undergoing fruiting (Table 1). Also, in other communities of mesophile deciduous forests, e.g in the Niepołomice Forest in southern Poland, the geophytes finished their flowering periods with the full development of the foliage (Klein 1977).

It should be noted that in the studied permanent plot there were several microhabitats where despite the maximum coverage already recorded in the tree layer, the geophytes were still present (Table 1). This fact may be influenced by the presence of sunflecks. At the floor of deciduous forests, with developed foliage, the sunflecks, although rare, provide up to 55% of the PPFD (Chazdon 1988). The amount of the sunflecks results from the crown geometry on the one hand, but on the other hand it can also change dynamically, e.g. under the influence of wind. It was twice noticed within the permanent plot (Figure 4B). It can be assumed that the importance of wind as a factor facilitating the penetration of light into the forest floor increases in the upper parts of the mountain ridges, along with the observed increase in wind speed. In the summit of the Łysogóry Range, the average annual wind speed is by approx. 1.5 $m \cdot s^{-1}$ greater than in the surrounding valley (Olszewski et al. 1994).

The obtained results confirm the adopted hypothesis. A simple light meter can be a valuable source of information on light conditions in the fertile beech forest understory and can be used in environmental research. With this we are able to interpret seasonal changes in the floristic composition and phenophases of species in the forest undergrowth, which are related to the percentage coverage of a tree layer and – consequently – to the amount of light reaching the forest floor. High ease and speed of the results acquisition make the simple portable light meter particularly useful in reconnaissance research and as a tool for fast and cheap supplementation of more sophisticated monitoring programmes.

References

Anderson, M.C. 1964a. Studies of the woodland light climate: I. The photographic computation of light conditions. *Journal of Ecology* 52(1): 27-41.

Anderson, M.C. 1964b. Studies of the woodland light climate: II. Seasonal variation in the light climate. *Journal of Ecology* 52(3): 643-663.

Baddour, O. and Kontongomde, H. (eds.) 2009. Guidelines for Plant Phenological Observations. World Climate Programme, WMO/TD No. 1484. World Climate Data and Monitoring Programme, WCDMP-No. 70. World Meteorological Organisation, Geneva, Switzerland, 16 pp. Available online at: http://www.wmo.int/pages/prog/wcp/wcdmp/documents/wmo-wcdmp-no70.pdf

Braun-Blanquet, J. 1964. Pflanzensoziologie, Grundzüge der Vegetationskunde [Phytosociology, Fundamentals of the Syntaxonomy]. 3. Aufl. Springer, Wien-New York, 865 pp. (in German).

Canham, Ch.D. and Burbank, D.H. 1994. Causes and consequences of resources heterogeneity in forests: interspecific variation in light transmission by canopy trees.

Canadian Journal of Forest Research 24(2): 337-349. doi: 10.1139/x94-046

Chazdon, R.L. 1988. Sunflecks and their importance to forest understorey plants. *Advances in Ecological Research* 18: 1-63.

Comeau, P.G. 2000. Measuring light in a forest. Series: *Extension Note* 42. British Columbia Ministry of Forest, Research Branch, Victoria, 7 pp. Available online at: htps://www.for.gov.bc.ca/hfd/pubs/En.htm Last accessed on: 05-11-2016)

Comeau, P.G. Gendron, F. and Letchford, T. 1998. A comparison of several methods for estimating light under a paper birch mixed wood stand. *Canadian Journal of Forest Research* 28(12): 1843-1850. doi: 10.1139/x98-159.

Daniels, F. 1956. Energy efficiency in photosynthesis. *In*: A. Hollaender (Ed.), Radiation Biology, 3rd edn. McGraw-Hill, New York, p. 259-292.

Dzwonko, Z. 2007. Przewodnik do badań fitosocjologicznych [Phytosociological Researches Guide]. Sorus, Instytut Botaniki Uniwersytetu Jagiellońskiego, Poznań-Kraków, 308 pp. (in Polish).

Engelbrecht, B.M.J. and Herz, H.M. 2001. Evaluation of different methods to estimate understorey light conditions in tropical forests. *Journal of Tropical Ecology* 17(2): 207-224. doi: 10.1017/S0266467401001146

Faliński, J. 2001. Przewodnik do długoterminowych badań ekologicznych [Long-Term Ecological Research Guide]. Wydawnictwo Naukowe PWN, Warszawa, 672 pp. (in Polish).

Jennings, S.B., Brown, N.D. and Sheil, D. 1999. Assessing forest canopies and understorey illumination: canopy closure, canopy cover and other. *Forestry* 72(1): 59-73 doi: 10.1093/forestry/72.1.59

Kępińska-Kasprzak, M. and Mager, P. 2015. Thermal growing season in Poland calculated by two different methods. *Annals of Warsaw University of Life Science – SGGW, Land Reclamation* 47(3): 261-273. doi: 10.1515/sggw-2015-0030

Klein, J. 1977. Zmiany oświetlenia wnętrza lasu grądowego w powiązaniu z rozwojem liści drzew i krzewów w północnej części Puszczy Niepołomickiej [Changes in light conditions inside the oak-hornbeam stand forest in relation to the development of leaves of trees and bushes in the northern part of the Niepołomice Forest]. *Fragmenta Floristica et Geobotanica Polonica* 23(2): 201-214 (in Polish with English abstract).

Korhonen, L, Korhonen, K.T., Rautiainen, M. and Stenberg, T. 2006. Estimation of Forest Canopy Cover: a Comparison of Field Measurement Techniques. *Silva Fennica* 40(4): 577-588. doi: 10.14214/sf.315

Lieffers, V.J., Messier, C., Stadt, K.J., Gendron, F. and Comeau, P.G. 1999. Predicting and managing light in the understory of boreal forests. *Canadian Journal of Forest Research* 29(6): 796-811. doi: 10.1139/x98-165

Machado, J.L. and Reich, P.B. 1999. Evaluation of several measures of canopy openness as predictors of photosynthetic photon flux density in deeply shaded conifer-dominated forest understory. *Canadian Journal of Forest Research* 29(9): 1438-1444. doi: 10.1139/x99-102

Matuszkiewicz, W. 2014. Przewodnik do oznaczania zbiorowisk roślinnych Polski [Plant Communities in Poland Determining Guide]. Wydawnictwo Naukowe PWN, Warszawa, 531 pp. (in Polish).

Miller, D.H. 1959. Transmission of insolation through pine forest canopy as it affects the melting of snow. *Mitteilungender Schweizerischen Anstalt für das Forstliche Versuchswesen* 35: 57-79.

Olszewski, J.L., Szałach, G. and Żarnowiecki, G. 2000. Klimat [Climate]. In: S. Cieśliński, A. Kowalkowski (Eds.): Monografia Świętokrzyskiego Parku Narodowego [Świętokrzyski National Park Monograph], ŚPN, Bodzentyn – Kraków, p. 129-145 (*in Polish*).

Olszewski, J.L., Żarnowiecki, G. and Rzepka, H. 1994. Prędkość i kierunek wiatru na Świętym Krzyżu [Velocity and direction of wind on the Święty Krzyż Mt.]. *Monitoring Środowiska Regionu Świętokrzyskiego* 2, p. 55-59 (*in Polish with English abstract*)

Robakowski, P., Modrzyński, J., Niemczyk, M. and Zwaduch, P. 2000. Ażurowość i fotosyntetyczna gęstość strumienia fotonów w drzewostanach z odnowieniem jodły pospolitej (*Abies alba* Mill.) [Canopy density and photosynthetic flux density in the stands with the regeneration of Silver fir (*Abies alba* Mill.)]. *Opera Corcontica* 37: 506-510 (in Polish with English abstract).

Roussel, L. 1953. Recherches théretiques et pratiques sur la répartition en quantité et en qualité de la lumiére dans le milieu forestier, influence sur la vegetation [Theoretical and applied researches on the qualitative and quantitative distribution of the insolation in forests, an impact on the vegetation], Impr. G. Thomas, Nancy, 114 pp. (in French with English summary).

Runkle, E. 2006. Light it up! *GPN Magazine* 7: 30

Schemske, D.W., Wilson, M.F., Melampy, M.N., Miller, L.J., Verner, L., Schemske, K.M. and Best, L.B. 1978. Flowering ecology of some spring woodland herbs. *Ecology* 59(2): 351-366

Słomka, J. and Dunikowski, S. 1959. Wstępne badania nad polem światła w dnie lasu [Preliminary research on the field of light on the forest floor]. *Prace IBL* 200: 51-64 (in Polish).

StatSoft, 2003. Statistica (data analysis software system), version 6.1, StatSoft, Inc., Tulsa, OK.

Szafer, W. 1922. O fenologicznych porach roku w Polsce [Phenological seasons in Poland]. *Kosmos* 47(1–3): 371–411 (in Polish).

The Plant List. 2013. The Plant List version 1.1. Available online at: http://www.theplantlist.org. Last accessed on: 30-08-2015.

Thimijan, R.W. and Heins, R.D. 1983 Photometric, radiometric and quantum light units of measure: A review of procedures for interconversion. *Hortscience* 18(6): 819-822

Urban, O., Janouš, D., Acosta, M., Czerný, R., Marková, I., Navrátil, M., Pavelka, M., Pokorný, R., Šprtová, M., Zhang, R., Špunda, V., Grace, J. and Marek, M.V. 2007. Ecophysiological controls over the net ecosystem exchange of mountain spruce stand. Comparison of the response in direct vs. diffuse solar radiation. *Global Change Biology* 13(1): 157-168. doi: 10.1111/j.1365-2486.2006.01265x

van Eimern, J. 1987. Vergleich der strahlungsverhältnisse über einem Buchenwald, zwei Kieferwäldern und einer Grasfläche [Comparison of the radiation above a beech forest, two pine forests and a grass covered surface]. *International Journal of Biometeorology* 31(3): 217-235 (in German with English abstract). doi: 10.1007/BF02188926

Winn, M.F., Palmer, A.J., Lee, S.-M. and Araman, P.A. 2016. ForestCrowns: a transparency estimation tool for digital photographs of forest canopies. e-Gen. Technical Report SRS–215. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station, 10 pp. Available online at: https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs215.pdf Last accessed on: 10-03-2018.

Zang, R., Tao, J. and Li, Ch. 2005. Within community patch dynamics in a tropical montane rain forest of Hainan

Island, South China. *Acta Oecologica* 28(1): 39-48. doi: 10.1016/j.actao.2005.02.001

Zarzycki, K., Trzcińska-Tacik, H., Różański, W., Szeląg, Z., Wołek, J. and Korzeniak, U. 2002. Ecological indicator values of vascular plants of Poland. *In*: Z. Mirek (Ed.) Biodiversity of Poland 2. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków, 183 pp.

Zielińska, K.M., Kiedrzyński, M., Grzyl, A. and Rewicz, A. 2016. Forest roadsides harbor less competitive habitats for a relict mountain plant (*Pulsatilla vernalis*) in lowlands. *Scientific Reports* 6(31913). doi: 10.1038/srep31913