

## Comparison of output results from two programmes for hemispherical image analysis: Gap Light Analyser and WinScanopy

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**ABSTRACT:** We compare the results of the analysis of hemispherical images (of a broadleaved and a coniferous forest) obtained using the Gap Light Analyser (GLA) software and the results obtained by analyzing the same images with the aid of WinScanopy. The two packages were used to calculate relative total, relative diffuse and relative direct transmittance, canopy openness, and leaf area index. Our aim was to find out whether it is possible to compare the studies using different software packages for determining light conditions. The binary pixel classification of images of canopy and sky was performed automatically (in the case of Gap Light Analyser, using the SideLook programme). The threshold values determined by the SideLook programme were lower compared to the WinScanopy, which was also reflected in the evaluated output results. There was a strong positive correlation between the results obtained with the two software packages ( $R^2$  ranges from 0.814 to 0.999). However, when the Gap Light Analyser analysis was applied to the threshold values obtained with the SideLook, the output results mostly manifested systematic differences in comparison with the output results obtained using the WinScanopy. Using the same threshold value in both programmes, the differences between the output values were quite small (a minimum of  $0.038 \text{ m}^2 \cdot \text{m}^{-2}$  for LAI in the spruce forest and a maximum of 0.738% for total relative transmittance also in the spruce forest). The differences in some characteristics were statistically significant, on the other hand, both the photo series had only the identical direct transmittance values. The observed differences can be explained by differences in the calibration of the used camera-lens pair, different image registration techniques and different theoretical background and models used in the two software packages. It follows that it is also necessary to be aware of possible differences when comparing the outputs of the two compared software packages analyzing photos obtained applying the same methodical approach.

**Keywords:** analyses; Gap Light Analyser; hemispherical photography; light; WinScanopy

Solar energy is the driving force for essentially all processes occurring in ecosystems, forests included. The canopy of trees controls abiotic as well as biotic energy flows in forest ecosystems, and consequently, the emergence, survival, and growth of plants in the understorey (e.g. DOBROWOLSKA 2008; VAL-LADARES, NIINEMETS 2008; BARNA et al. 2009; BÍLEK et al. 2009; WAGNER et al. 2009). Determining light conditions in the forest understorey provides important information about growth conditions

for plants growing in this environment (JARČUŠKA 2008).

The evaluation of a light regime in the forest environment by direct measurement is time and cost demanding – due to considerable time and spatial variability of this environmental factor. For this reason, many indirect methods have been developed for determining the amount of solar radiation accessible in the understorey through assessing the crown layer structure of the stand, such as e.g. the

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moosehorn, spherical densitometer, canopy scope – for details see JENNINGS et al. (1999) and BROWN et al. (2000). One of them is the method for evaluation of photos taken using 180° fish-eye lenses.

Recently, numerous software packages (commercial as well as freeware programmes) were developed that were consequently used in a broad range of applications (JARČUŠKA 2008). For comparability it is essential that two systems give equivalent results. There is only scarce information in literature about the comparison of different software (Hemiphot vs. Pamap GIS in FRAZER et al. 1997). Therefore, our aim was to compare canopy characteristics and below-canopy light conditions obtained by the analysis of hemispherical photos. The comparison was made between the freeware Gap Light Analyser (GLA) 2.0 (FRAZER et al. 1999; used e.g. in ŠPULÁK 2008; SZWAGRZYK, SZEWCZYK 2008; GLONČÁK 2009) and the commercial software package WinScanopy 2006b (Régent Instruments, Canada; e.g. in ROZENBERGAR et al. 2007; SZYMURA et al. 2007; PETRITAN et al. 2009).

## MATERIALS AND METHODS

The photos were taken in two localities (permanent research plots) situated in Central Slovakia, the Western Carpathians Mts.: (i) in European beech (*Fagus sylvatica* [L.] stands in the Badín primeval forest (48°41'N, 19°03'E; 750 m a.s.l.) in the Kremnické vrchy Mts. and (ii) in Norway spruce (*Picea abies* [L.] Karst.) stands under the upper forest line in the mountain massive Prašivá (48°52'N, 19°18'E; 1,300 m a.s.l.) in the Nízke Tatry Mts. The beech primeval forest (394 trees.ha<sup>-1</sup>, 794 m<sup>3</sup>.ha<sup>-1</sup>, 42.3 m<sup>2</sup>.ha<sup>-1</sup> of stems with > 7 cm dbh) has a multi-layered structure with rather low light transmittance. The photos were taken in July 2008, on a permanent research plot (PRP) 200 × 250 m in size, at knots of a grid 25 × 25 m covering the plot. We made 99 images from which we chose 20 in such a way as to obtain a uniform cover for the entire light gradient on the PRP. The studied spruce forest has a mostly mono-layered structure and an open canopy typical of high-montane and subalpine Norway spruce forests

(650 trees.ha<sup>-1</sup>, 314 m<sup>3</sup>.ha<sup>-1</sup>, 33.5 m<sup>2</sup>.ha<sup>-1</sup> of stems with > 7 cm dbh). This locality was provided with a regular grid of 30 circular sample plots, each having an area of 400 m<sup>2</sup>, spaced by 70 m. In August 2008 we took images at the centre of each sample plot. Four of them were excluded from our analysis, due to lacking a sharp contrast between the sky and the foliage.

Hemispherical photos were taken under completely overcast sky conditions (Badín) and when the sun was under the skyline (Prašivá) in order to minimize glare from direct sunlight. We used a Nikon P5000 digital camera and Nikon FC-E8 fish-eye lens converter with 183° view angle from Régent WinScanopy accessories. The camera was installed at a height of 1.3 m on a self-levelling mount. The aperture width and shutter speed were adjusted automatically. Photographs were underexposed (by 0.7 EOV) to ensure the contrast between sky and canopy. For basic characteristics of the analyzed series of images see Table 1.

Pixel classification into canopy and sky (thresholding) is a critical operation in the analysis of hemispherical images. Accurate segmentation is of extreme importance, because the outcome of this step will have a significant influence on all subsequent processing (JONCKHEERE et al. 2005). This classification provides input data for the subsequent canopy analysis. To avoid subjectivity due to manual thresholding, the threshold value was set automatically. In the programme WinScanopy we used pixel classification based on grey scale (so called *global threshold*). As the freeware GLA does not allow to classify the pixels automatically, the threshold value for image analysis with this software was determined with the aid of shareware SideLook 1.1 (NOBIS 2005; NOBIS, HUNZIKER 2005) using all the offered colour channels (blue, green, red and grey, respectively). Values of user-supplied input variables (see FRAZER et al. 1999; ANONYMOUS 2007) were set the same for both programmes. To remove the influence of different threshold values (see the results) on output values provided by the two compared programmes, hemispherical photos in the programme GLA were also

Table 1. Basic statistical characteristics of the analyzed series of photos (relative total transmittance – outputs from the WinScanopy analysis)

Locality	Mean	SD	Median	Min.	Max.	<i>n</i>
Badín	5.80	3.26	4.82	1.44	12.38	20
Prašivá	18.21	13.76	13.36	3.52	56.41	26

SD – standard deviation

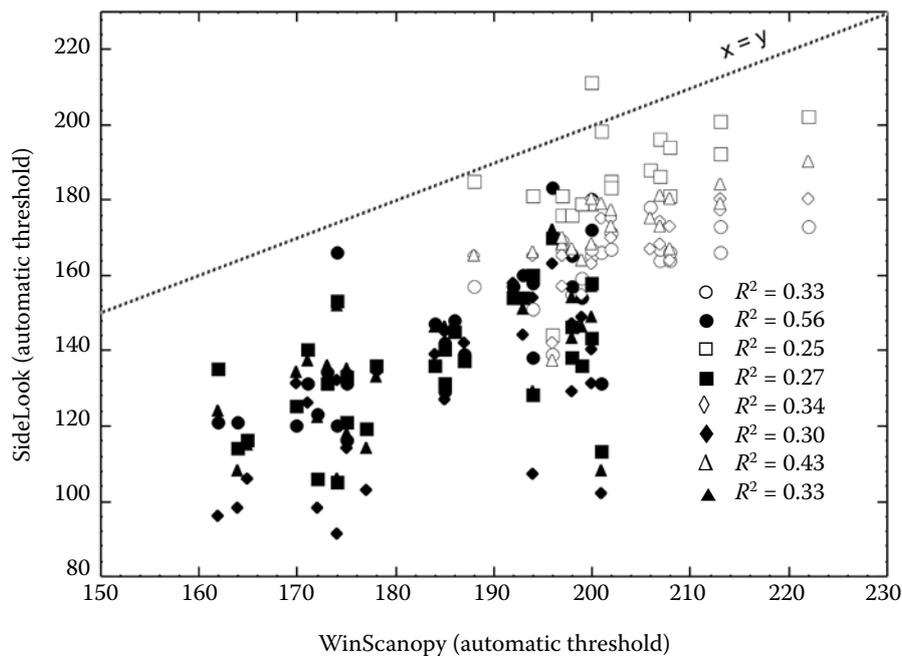


Fig. 1. Scatter plots of the automatically generated thresholds obtained with the SideLook programme (blue (○●), green (□■), red (◇◆) and gray (△▲)) channel; open symbols are for beech forest, solid symbols for spruce forest in relation to the threshold values obtained by the WinScanopy programme. The calculated regression lines (not shown) (all statistically significant at  $P < 0.05$ ) had intercepts not significantly different from zero and slopes not significantly different from unity

analyzed based on threshold values determined with the aid of the WinScanopy.

The relations between output results from the two compared programmes were tested through Pearson's correlation and through linear regression. We tested the following parameters: canopy openness (%), leaf area index ( $\text{m}^2 \cdot \text{m}^{-2}$ ; LAI 5 Ring in GLA compared to LAI 2000 Lin in WinScanopy) and relative amount of direct, relative amount of diffuse and relative amount of total light (% Trans Direct, Diffuse and Total in GLA compared to Direct, Indirect and Total Site Factor in WinScanopy, respectively). Standard  $t$ -tests were applied to find out whether the slopes and intercepts of the regression lines differed significantly from unity and zero, respectively. All statistical analyses were done at the 5% probability level, using Statistica 6.0 (StatSoft, USA).

## RESULTS AND DISCUSSION

The threshold values determined by the SideLook programme using the offered colour channels were lower (underestimated) in comparison with the threshold values calculated by the WinScanopy (Fig. 1). In the beech forest, threshold values calculated with the green channel were the closest to the line  $y = x$ , in the spruce forest (mostly) it was the blue channel. However, the  $t$ -test showed that the slopes of these regression lines did not differ significantly from unity and their intercepts did not differ sig-

nificantly from zero (from the 1:1 relationship). The absorption of leafy material is the highest and sky scattering is the lowest in the blue channel, so using this channel we can obtain a higher contrast between the tree crowns and the background compared to the other ones (LEE et al. 1983; NOBIS, HUNZIKER 2005). However, FRAZER et al. (2001) suggested that the digital system was more sensitive to sky conditions than the film system and that no single colour plane seemed to be able to improve the contrast between the sky and the canopy elements, in addition, digital photos were extremely difficult to set the threshold. Therefore the digital system produces less replicable results compared to the film system (FRAZER et al. 2001).

Regression equations were calculated for the relative amount of total (TOT), diffuse (DIF) and direct (DIR) radiation transmitted through the crown canopy, for canopy openness (CO) and for leaf area index (LAI) (Table 2). In contrast to the varying raw threshold values, a strong positive correlation was identified between GLA and WinScanopy in all variables ( $R^2$  ranges from 0.814 to 0.999) and all regressions were found significant (at  $P < 0.05$ ). The images taken in the beech forest (Badín) and analyzed by the two programmes using the same threshold values showed insignificant differences between the regression line slope and unity and between the intercept and zero for TOT, DIR and CO. The differences in DIF and LAI were found significant (Table 2), in spite

Table 2. Regression coefficients (standard error in brackets) and percentage of explained variation ( $R^2$ ) obtained by comparing the results of the analysis of hemispherical images from beech forest (Badín) and spruce forest (Prašiva). The results obtained using GLA ( $y$ ) are compared with the results obtained by WinScanopy ( $x$ ) software package. The form of regression equation is  $y = a + bx$ . All regressions were statistically significant ( $P < 0.05$ ). In bold are intercepts not significantly different from zero and slopes not significantly different from unity ( $P > 0.05$ )

	Threshold for GLA from: WinScanopy			SideLook – blue channel			SideLook – green channel		
	intercept	slope	$R^2$	intercept	slope	$R^2$	intercept	slope	$R^2$
<b>Beech forest</b>									
TOT	<b>-0.062 (0.358)</b>	<b>1.069 (0.054)</b>	0.953	1.668 (0.669)	<b>1.139 (0.101)</b>	0.868	<b>0.529 (0.507)</b>	<b>1.100 (0.078)</b>	0.915
DIF	<b>-0.024 (0.122)</b>	1.036 (0.015)	0.996	3.295 (0.588)	<b>0.905 (0.072)</b>	0.892	<b>0.292 (0.386)</b>	1.105 (0.047)	0.966
DIR	<b>-0.123 (0.354)</b>	<b>1.077 (0.054)</b>	0.955	1.485 (0.646)	<b>1.167 (0.098)</b>	0.881	<b>0.482 (0.486)</b>	<b>1.105 (0.074)</b>	0.921
CO	<b>0.143 (0.080)</b>	<b>1.010 (0.017)</b>	0.995	2.201 (0.467)	<b>0.896 (0.098)</b>	0.814	<b>0.064 (0.291)</b>	1.152 (0.061)	0.949
LAI	0.279 (0.065)	0.903 (0.018)	0.993	<b>0.437 (0.284)</b>	0.753 (0.078)	0.829	<b>0.235 (0.289)</b>	<b>0.872 (0.079)</b>	0.863
<b>Spruce forest</b>									
TOT	0.565 (0.261)	<b>0.992 (0.012)</b>	0.997	3.153 (0.515)	<b>0.997 (0.023)</b>	0.987	4.015 (0.491)	<b>0.976 (0.022)</b>	0.987
DIF	<b>-0.233 (0.175)</b>	1.029 (0.008)	0.999	2.777 (0.578)	<b>1.023 (0.026)</b>	0.984	4.049 (0.612)	<b>0.989 (0.027)</b>	0.981
DIR	<b>0.336 (0.275)</b>	<b>1.001 (0.012)</b>	0.996	2.855 (0.517)	<b>1.008 (0.023)</b>	0.987	3.661 (0.493)	<b>0.989 (0.022)</b>	0.988
CO	<b>-0.189 (0.149)</b>	1.036 (0.011)	0.997	1.662 (0.476)	<b>1.064 (0.036)</b>	0.973	2.612 (0.523)	<b>1.022 (0.039)</b>	0.965
LAI	<b>-0.014 (0.037)</b>	<b>0.992 (0.015)</b>	0.994	<b>0.221 (0.123)</b>	0.793 (0.050)	0.909	0.263 (0.117)	0.758 (0.048)	0.909

TOT – total, DIF – diffuse, DIR – direct transmitted radiation, CO – canopy openness, LAI – leaf area index

Table 3. Average values of absolute differences (standard error in brackets) obtained by comparing the results of the analysis of hemispherical images from beech forest (Badín) and spruce forest (Prašivá). The results obtained using GLA are compared with the results obtained by WinScanopy software package

Mean $\Delta$ between GLA and WinScanopy			
	Threshold for GLA from: WinScanopy	SideLook – blue channel	SideLook – green channel
<b>Beech forest</b>			
TOT	0.548 (0.144)	2.475 (0.329)	1.196 (0.225)
DIF	0.251 (0.045)	2.565 (0.200)	1.119 (0.134)
DIR	0.608 (0.157)	2.408 (0.369)	1.169 (0.247)
CO	0.189 (0.020)	1.724 (0.121)	0.776 (0.080)
LAI	0.072 (0.011)	0.458 (0.036)	0.235 (0.029)
<b>Spruce forest</b>			
TOT	0.738 (0.104)	3.099 (0.310)	3.593 (0.303)
DIF	0.443 (0.065)	3.261 (0.215)	3.820 (0.225)
DIR	0.741 (0.118)	2.987 (0.331)	3.471 (0.317)
CO	0.322 (0.049)	2.464 (0.172)	2.895 (0.179)
LAI	0.038 (0.006)	0.276 (0.030)	0.319 (0.032)

TOT – total, DIF – diffuse, DIR – direct transmitted radiation, CO – canopy openness, LAI – leaf area index

of rather small average differences in these variables ( $0.251 \pm 0.045\%$  and  $0.072 \pm 0.011 \text{ m}^2 \cdot \text{m}^{-2}$  for DIF and LAI, respectively; mean  $\pm$  standard error (SE); Table 3). Neither did the values of TOT, DIR and LAI obtained for images classified with the threshold values obtained by SideLook with green channel (Table 2) and TOT, DIR with grey channel (data not shown) differ significantly from the 1:1 relationship.

In the case of hemispherical photos of the spruce forest (Prašivá) analyzed by the two programmes using the same threshold values, only the values of DIR and LAI did not differ significantly from the 1:1 relationship. The slopes of the other compared (GLA + SideLook vs. WinScanopy) characteristics (except of LAI – due to the logarithmic relationship between CO and LAI) did not differ significantly from unity, on the other hand, the values of intercepts differed from zero significantly (Table 2). The largest average difference was obtained comparing the outputs of DIF from GLA + SideLook (green channel) and WinScanopy –  $3.820 \pm 0.225\%$  (mean  $\pm$  SE; Table 3).

With the same threshold value, we also expected the CO output values to be independent of the analyzing software for images of the spruce forest. The observed differences could be due to the fact that the programme WinScanopy analyzed the photos with a by-default-set calibration of the used pair of camera-

lens (view angle and lens distortion; ANONYMOUS 2007); however GLA worked with an entire  $183^\circ$  field of view and a polar-projection distortion of the used fish-eye converter (FC-E8 was designed to produce this type of projection; on the other hand, FRAZER et al. [2001] showed that this lens did not conform to its design specifications). The result of the study of INOUE et al. (2004a) manifested that the calibrated estimate of canopy openness was comparatively low (0.344%) but significantly higher than the uncalibrated value (also for FC-E8). The authors next found that the calibration effect would be different among light environment estimates – the differences are getting larger and more frequent with the increasing presence of gaps in the canopy layer. If we had calibrated the view angle and lens distortion (for the used converter) for GLA, the difference in the output values between the compared software packages would have been larger than the results we obtained, especially for the images from the spruce forest with a broader light gradient. The presented differences between GLA and WinScanopy are likely due to an extra user-error associated with (GLA) image registration techniques (there is more human control in GLA than in WinScanopy) as well as due to the differences in the theoretical background and models used in the two programmes themselves. Inadequate image registration techniques may account for a

significant portion of the analytical error introduced during hemispherical image processing (FRAZER et al. 1997). We did not succeed in separating the three error sources, so further study is necessary. Because no direct measurements of the discussed characteristics were made, we cannot declare which of the two methods is more reliable.

The prerequisites for comparing the results of different studies analyzing hemispherical images are careful observation and precise description of the proposed methodical approaches (HALE, EDWARDS 2002). This method of indirect determination of light conditions is loaded with a possibility of errors at each step, beginning with scanning up to the processing of the results (HALE, EDWARDS 2002; JONCKHEERE et al. 2004). Apart from the camera exposure setting (see ZHANG et al. 2005), the results are also influenced by the camera type and the image size (INOUE et al. 2004b). Automatic image pixel segmentation is more objective than the interactive (manual) application of a visually selected threshold for the whole image (JONCKHEERE et al. 2005); on the other hand, the algorithms used for determining threshold values in the compared applications need not bring the same outputs (see Fig. 1 and Table 2).

## CONCLUSION

Our results show that the outputs obtained by applying two different programmes for the hemispherical image analysis (GLA and WinScanopy) were not identical in the case of all compared characteristics of accessible light and in the case of crown layer structure in spite of the fact that the analyzed photos were taken by the same method (simulated by using the same photos in compared software applications). We can see that the discussed outputs are influenced most dramatically by the threshold values set for pixel classification. After the influence of different threshold values had been eliminated, the differences between the compared output values turned out quite small. Nevertheless, they remained still significant in some characteristics. The differences between the compared characteristics can be explained by different calibration of the used camera-lens pair (view angle and lens distortion of the fish-eye converter), different image registration techniques and different theoretical background and models in the two different packages. These results have also confirmed that it is required to use the strict (and standardized) protocol across the whole process, beginning with sampling up to the image processing

and evaluation. Therefore, it is essential to be aware of possible differences when comparing the outputs from two different software packages used for the analysis of images obtained according to the same methodical approach.

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