

ANALYSIS OF CANOPY CLOSURE IN THE DINARIC SILVER FIR – BEECH FORESTS (*OMPHALODO-FAGETUM*) IN CROATIA USING HEMISPHERICAL PHOTOGRAPHY

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Abstract

Hemispherical (or fisheye) photography has wide applicability in various forms of environmental monitoring, modeling and research. Since understory light conditions are a very important determinant of vegetation pattern, during extensive field survey in the Dinaric part of the silver fir – beech forest area of distribution, hemispherical photographs of forest canopy were taken at 151 plots. The photographs were scanned, classified based on the quality of their contrast and analysed with Gap Light Analyzer software. The percentages of canopy openness and LAI (leaf area index) were calculated. The results were analysed with descriptive statistics, linear regression and CART analyses. For the portion of the sampled area a satellite ETM+ image was available which enables comparison of canopy features with NDVI (Normalized Difference Vegetative Index). Statistically significant negative correlation was detected between canopy openness and NDVI for best-contrasted photographs, while LAI was positively correlated with NDVI for all analysed photographs, and negatively correlated with the number of present plant species for best-contrasted photographs. According to CART analyses LAI was an important predictor variable for estimating the number of present plant species. The results obtained point to the methodological steps that have to be improved, and also direct the future investigations in order to take most from the hemispherical photographs data.

Izveček

Fotografija hemisfere je vsestransko uporabna za različne monitoringe, modeliranja in raziskave okolja. Ker so svetlobne razmere v plasti pod krošnjami zelo pomembna determinanta vegetacijskega vzorca, sem pri raziskavi v območju dinarskih jelovo-bukovih gozdov Hrvaške posnel fotografije hemisfere drevesnih krošenj na 151 vzorčnih ploskvah.

Fotografije sem skeniral in klasificiral na podlagi kvalitete kontrasta in analiziral s programom Gap Light Analyzer Software. Izračunal sem odstotke odprtosti krošnje in LAI (leaf area index). Rezultate sem analiziral z deskriptivno statistiko, linearno regresijo in analizami CART. Za del vzorčenega območja so bili na voljo satelitski posnetki ETM+, ki so mi omogočili primerjavo lastnosti krošenj z NDVI (Normalized Difference Vegetative Index).

Pri fotografijah z najboljšim kontrastom sem opazil statistično značilno negativno korelacijo (odvisnost) med odprtostjo krošnje in NDVI, medtem ko je bil pri vseh analiziranih fotografijah LAI v pozitivni korelaciji z NDVI in pri fotografijah z najboljšim kontrastom v negativni korelaciji s številom prisotnih rastlinskih vrst.

Po analizah CART je bil LAI pomemben kazalnik v oceni števila prisotnih rastlinskih vrst. Rezultati, ki sem jih dobil, so pokazali, katere metodološke korake moramo izboljšati, da bi usmerili bodoča raziskovanja h kar najširši uporabi fotografije hemisfere.

Key words: *Omphalodo-Fagetum*, hemisphere photography, canopy, CART, LAI, NDVI, Croatia

Ključne besede: *Omphalodo-Fagetum*, fotografija hemisfere, krošnja, CART, LAI, NDVI, Hrvaška

INTRODUCTION

The first hemispherical (or fisheye) lens was designed by Hill (1924) for study of cloud formation. Forest ecologists started using the methods some 35 years later (Evans & Coombe 1959). Develop-

ment of procedures for automated image analyses started with Jupp & al. (1980) and is still going through the individual (ter Steege 1997, Brunner 2002) and team (Frazer & al. 1999) university-based efforts and fully commercial programs (Anonymous 1999, 2003).

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Analyses of the hemispherical photographs can provide various types of information from canopy openness and leaf area index to the amount of direct or diffuse solar radiation transmitted by the canopy. Understory light conditions are a very important factor for floristic composition in forests (Rankin & Tramer 2002). To examine the dependence of vascular plant diversity to understory light conditions in the surveyed forest association, I made hemispherical photographs of the canopy during the extensive field survey in the dinaric part of the silver fir – beech forest (*Omphalodo-Fagetum*) in Croatia. Canopy openness and leaf area index (LAI) were calculated as two measures of available light, and statistically analysed to establish possible correlations with the number of present plant species and normalized difference vegetative index (NDVI) acquired from the satellite image. Further, a Classification tree model of plant diversity was developed using the altitude, slope and aspect, besides the LAI, as predictor variables to evaluate the importance of the canopy feature (i.e. LAI) in comparison with other important environmental factors included in the analyses. Finally, I tried to identify methodological steps that have to be im-

proved in future employment of hemispherical photography in forest ecology research in order to gain the most from it.

METHODS

The research was carried out in the Dinaric silver fir-beech forests of the association *Omphalodo-Fagetum* (Tregubov 1957) Marinček et al. 1993 (Marinček & al. 1992) on a limestone as a parent rock. All in all, 151 circular plots with 25 metres diameter were surveyed (Figure 1). Data about the floristic composition were gathered and hemispherical photographs of forest canopy were taken in the centre of each plot during the 2002 growing season. Hemispherical photographs were taken using the Sigma 8mm fish-eye lens mounted on a Nikon F601 camera body using the tripod with levelling head (Figure 2), which ensured horizontal position of the lens, orientated with the upper edge of the negative towards the magnetic north. Konica

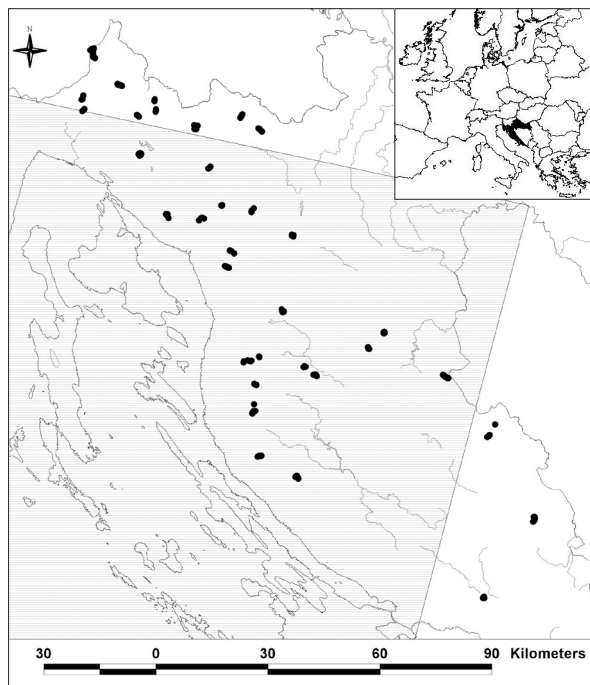


Figure 1: Geographical position of 151 plots surveyed. Shaded rectangle indicates the position of georeferenced Landsat ETM+ satellite image covering 91 plots.

Slika 1: Geografski položaj 151 opazovanih ploskev. Osenčena površina nakazuje položaj georeferencirane slike Landsat ETM+ satelita, ki pokriva 91 ploskev.



Figure 2: Sigma 8mm fisheye lens mounted on Nikon F601 camera body on the tripod with levelling head that ensures horizontal position of the lens.

Slika 2: Fotoaparat Nikon F601 z objektivom Sigma 8 mm (ribje oko), pritrjen na stativu z glavo, ki omogoča horizontalni položaj fotoaparata.

400 ASA true-colour film was used. The negatives were scanned with a Minolta Dimage Scan Elite II scanner and analysed with Gap Light Analyzer (GLA) software (Frazer et al. 1999).

The best hemisphere photographs, with high contrast, can be obtained when taken under conditions with even backlighting, that is: just before sunrise, just after sunset or under an evenly overcast sky. But, as mentioned by some authors (Diaci et al. 1999) ideal backlighting conditions are not very often found in the field. As a part of a bigger team in the field, for practical reasons I took the photographs within one hour after I reached the sampled plots (that was the average time the team spent on each plot), trying to catch the best backlighting conditions. Sometimes it was impossible to avoid direct sunlight or its reflection in the photographs. Confidence in separating pixels into sky and non-sky classes decreases with the lower contrast of hemispherical photographs. Therefore, I have classified the photographs based on a subjective judgment of quality of their contrast into three classes (good, moderate and low quality contrast) in order to decrease the possibility of masking significant correlations, later in analysis, with low quality photographs. Six photos I excluded from further analyses. Furthermore, I tried to decrease the bias caused by direct sunlight in photographs by manually correcting the obvious sun reflections from branches, broad leaves and bark of the trees (especially of beech) and bare rocks emerging from the ground.

Prior to calculation of canopy features, for each photograph the threshold value was manually set, in GLA software, upon which separation of image pixels into sky and non-sky classes was done (Figure 3).

Using the sky-region grid compound of 36 azimuth and 9 zenith regions (Figure 4), taking into account polar projection distortion of the lens (without any additional calibrating), two canopy characteristics were calculated for each photograph:

1. The Leaf area index, which can be simply defined as the amount of leaf surface area per unit of ground area. It describes the photosynthetic and transpirational surface of plant canopies. Here, I used a calculated effective leaf area index integrated over the zenith angles 0 to 60° (referred to as LAI 4 in the GLA software).

2. Canopy Openness, i. e. a percentage of open sky seen from beneath a forest canopy, or as we call it "a frog perspective".

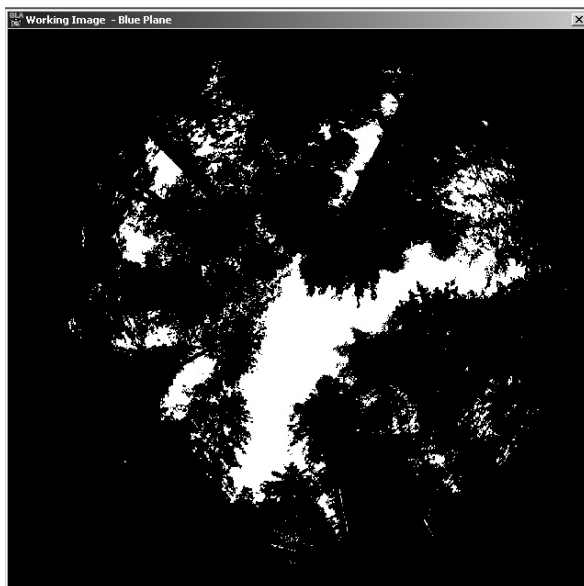


Figure 3: Hemispherical photograph after setting the threshold value upon which classifications of pixels into sky and non-sky classes were done.

Slika 3: Hemisferična fotografija po določitvi mejne vrednosti pikselov (pik) po katerih so bile določene (klasificirane) pike, ki predstavljajo nebo in tiste, ki predstavljajo ostale objekte.

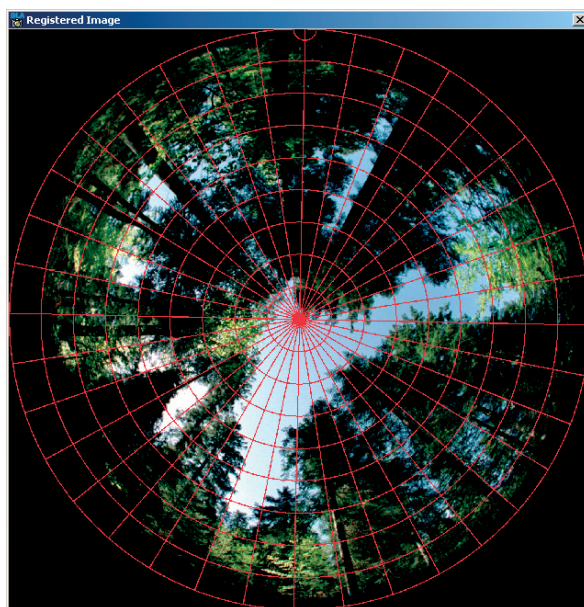


Figure 4: Sky-region grid compound of 36 azimuth and 9 zenith regions used for calculation of Leaf Area Index and Canopy Openness (projection distortion of the lens was taken into account, therefore each region represents an equal area).

Slika 4: Mreža področja neba razdeljena na 36 azimutnih in 9 zenitnih pasov, ki je uporabljena za izračun indeksa listne površine in zastiranja krošenj (popačenje projekcije je upoštevano in vsak razdelek mreže predstavlja enako površino).

The calculated values were analysed with descriptive statistics, simple linear regression and CART analyses.

For a portion of the sampled area satellite ETM+ image was available (Figure 1) covering 91 plots.

After ortho-rectification of the image, it was incorporated into the GIS database that enabled comparison of canopy features and the number of plant species with NDVI (Normalized Difference Vegetative Index) derived from bands 3 and 4 of ETM+ image for 91 sampled plots (of which six were excluded from the analyses, as previously stated).

Four regression analyses were performed: Canopy openness and LAI vs. number of plant species and NDVI. For CART analyses the number of present plant species was reclassified into five classes (1: 17–24, 2: 25–33, 3: 34–40, 4: 41–48, 5: 49–56). This new variable (NoSP5) was the dependent variable used for building the Classification tree with four predictor variables (altitude, slope, aspect and LAI). Because of its circular nature, the terrain aspect was transformed into a continuous north-south gradient (northness) by calculating the cosine of aspect values (Guisan et al. 1999). Analyses were performed on the best-contrasted photographs from the complete set (151 plot), making the size of the sample equal to 64 plots.

Classification tree analyses – CT produces series of nested “if-then-else” splits for separation of cases into groups (class of number of present plant species in our case). CART-style exhaustive search for univariate splits as a split selection method was used with Gini measure of goodness of fit and prune of misclassification error as a stopping rule (i.e. selection of the right-sized tree) in the process of building a binary decision tree in STATISTICA 6.0 software. Unlike other methods, such as multiple regressions, through its recursive partitioning algorithm CT can use one explanatory variable more than once. This way it can work with data that might have multiple structures. A further advantage of CT is that it is extremely robust with respect to outliers. They have a weight of one among n , or, in case they are outliers in the response variable that is under consideration for creating a new split, they will be separated into their own node. There they will no longer affect creation of the rest of the decision tree. There are also some drawbacks, like creation of later splits in the tree, that are based on fewer cases than the initial ones. Further, the decision tree can obscure the simple structures in the data. Defining criteria that will stop splitting is necessary to avoid over-fitting the input data that will

decrease efficiency of the model on new data. More thorough background information about the CT can be found in Breiman & al. (1984) and Vaysières & al. (2000).

RESULTS

The mean calculated canopy openness was 6.14% (s.d. = 1.82) with values in range from 2.66 to 13.72%. Mean calculated LAI value was 3.41 (s.d. = 0.45) with values in the range from 1.97 to 4.62. All the above given values refers to complete sets of photographs (good, moderate and low contrast). Values for separate sets of photographs are not shown, because these values highly depend on the structure of the stands - which was not analysed here - and not only on the contrast quality of the photographs.

Statistically significant negative correlation ($P = 0,05$ level) was detected between canopy openness and NDVI for the best-contrasted photographs, while LAI was positively correlated with NDVI for all analysed photographs, and negatively correlated with the number of present plant species for the best-contrasted photographs (Table 1).

Table 1: Simple linear regression coefficients ($P = 0,05$). LAI – Leaf Area Index; NDVI – Normalized Difference Vegetative Index; CAN – Canopy Openness; NoSP – number of plant species present on surveyed circular plots (area = 490m²). QC – quality of contrast, where 1 indicates best-contrasted hemispherical photographs (n. s. – not significant coefficient).

Tabela 1: Koeficienti linearne regresije ($P = 0,05$). LAI - Indeks listne površine; NDVI - Vegetativni indeks normirane razlike; CAN - Zastiranje krošenj; NoSP - število rastlinskih vrst na okrogli raziskovalni ploskvi (površina = 490 m²). QC - kakovost kontrasta, pri čemer 1 pomeni najbolj kontrastne hemisferične fotografije (n. s. - koeficient ni statistično značilen).

	QC = 1,2,3 (N = 85)	QC = 1,2 (N = 65)	QC = 1 (N = 32)
LAI vs. NDVI	0,29	0,37	0,61
LAI vs. NoSP	n. s.	n. s.	- 0,39
CAN vs. NDVI	n. s.	n. s.	- 0,37
CAN vs. NoSP	n. s.	n. s.	n. s.

The final classification tree for number of present plant species is shown in Figure 5. The most important predictor variable was altitude, with maximum ranking of importance = 100, and chosen as

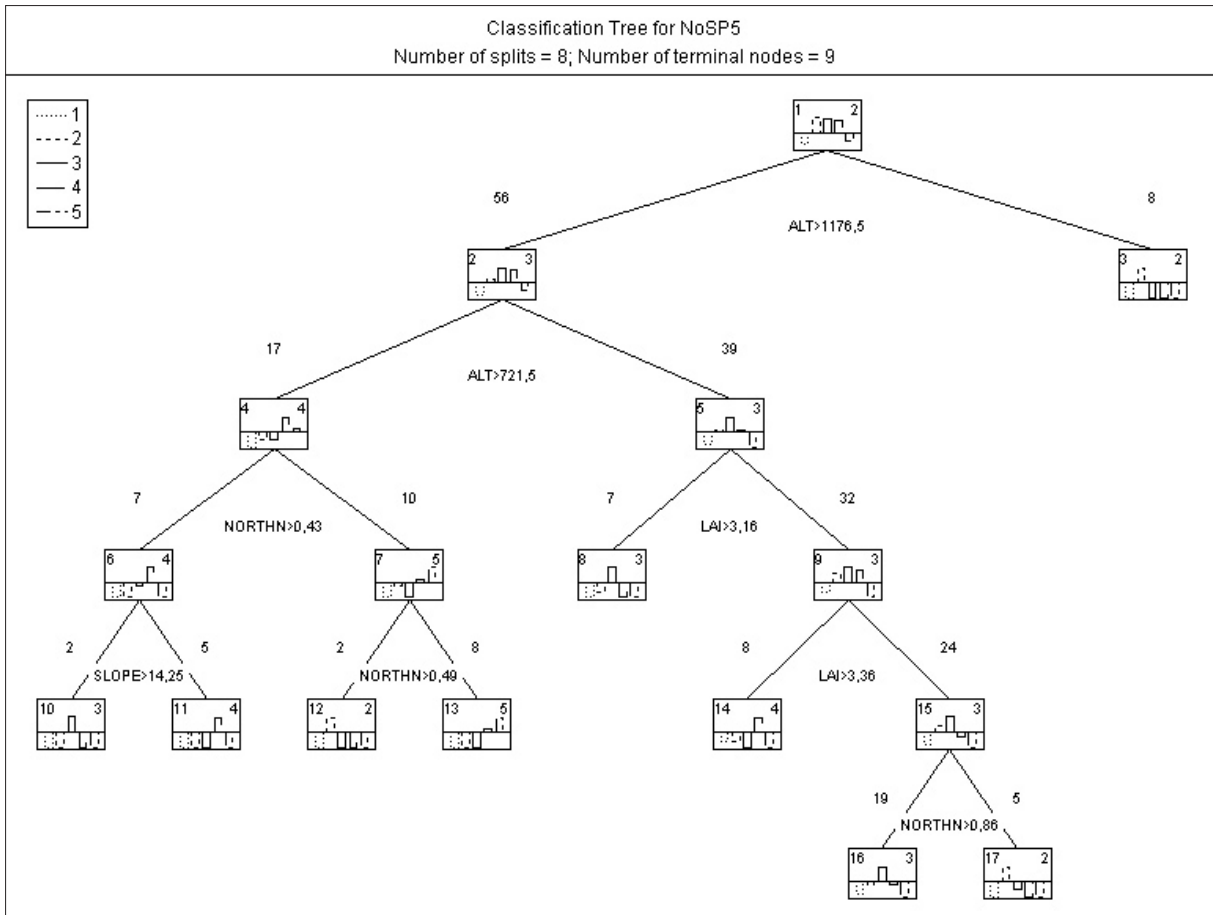


Figure 5: Classification tree model for number of plant species developed on learning set of 64 best contrasted hemisphere photographs, and four estimators (ALT – altitude; LAI – leaf area index; SLOPE – slope; NORTHN – northness of the aspect, see methods section). Numbers above nodes (rectangles) indicate the number of cases sent to that node. The number in the upper left part of the node is a node number, while that in the upper right corner denotes the predicted class (1 to 5, where 5 indicates maximum number of present plant species). In each node histograms indicate the proportions of cases in each class at node.

Slika 5: Model klasifikacije glede na število rastlinskih vrst, ki je bil izdelan na podlagi 64 najbolj kontrastnih fotografij hemisfere in štirih proučevanih dejavnikov (ALT – nadmorska višina; LAI – indeks listne površine; SLOPE – naklon; NORTHN – smer sever, glej poglavje metode). Številke nad sečišči (pravokotniki) predstavljajo število primerov, ki se vežejo na to sečišče. Številka v zgornjem levem delu sečišča predstavlja to sečišče; številka v zgornjem desnem kotu predstavlja predvideno klasifikacijo (1 do 5, pri čemer 5 predstavlja maksimalno število prisotnih rastlinskih vrst). V vsakem sečišču histogrami podajajo razmerja primerov vsake klasifikacije sečišča.

DISCUSSION

the decision rule in the two first splits in the CT. LAI was the second important predictor with importance = 93, and chosen as the decision rule in the right part of the tree with 39 cases. After the first two splits, 17 cases were sent to the left part of the tree and further classified based on their northness and slope values, with importance rankings of predictors 73 and 62 respectively. The classification tree correctly classified 48 (75%) cases from the input set.

The calculated values were similar to those found in the literature for canopy openness (Machado & Reich 1999, Brown & al. 2000, Englund & al. 2000, Frazer & al. 2001) and LAI (Frazer & al. 2001) of similar mature forest stands. However such comparisons should be made with caution because canopy characteristics are, besides the maturity and climate zone, dependent on the species structure

(broadleaved or coniferous) of the stands. Here, comparison is made just as rough control of the results in the process of adopting the methodology.

The detected negative correlation between canopy openness and NDVI for best-contrasted photographs and the positive correlation between LAI and NDVI for all photographs (Table 1) is in accordance with the results of Fuller (1999) who found positive correlation between NDVI and canopy closure – opposite to canopy openness – while LAI can be treated as a measure of canopy closure, hence the different trend of correlations. Increase of correlation between LAI and NDVI with the increase of image quality is obvious (Table 1), and emphasizes the problem of photograph acquisition under bright sun conditions that decrease the contrast of photographs.

Although canopy openness and LAI are highly significantly correlated ($r = -0,85$, $P < 0,01$, $N = 144$), significant correlation was not found between canopy openness and number of plant species, while for LAI it was (Table 1). This can be explained by the difference in calculated region for canopy openness and LAI. The region for calculating LAI index is in this case from 0° to 60° zeniths that exclude the marginal portion of the image. It is known that this marginal area (close to the horizon) is more subjected to lens aberrations (Diaci & Kolar 2000) and therefore to be of less accuracy than the central part of the image. It is also expected that solar radiation coming just above the understory herbaceous plants is of more importance for them than the solar radiation coming from the edges (horizon). According to the results of CT analysis, LAI was a more important predictor for estimating the plant richness than the slope and orientation of the terrain. This is not surprising, since it is well known that light is among the key factors affecting the understory floristic assemblage that can be seen for instance in Rankin & Tramer (2002) who examined a succession of understory species in dependence on the spatial dynamics of the gaps. See also Rankin & Tramer (2002) for a list of references on the topic.

Calculation of the leaf area index can be accomplished in many ways using different algorithms. Comparison of several methods can be found in Martens & al. (1993). Measuring to what extent the LAI used here is appropriate for the investigated forest (selectively logged mature stands of *Fagus sylvatica* and *Abies alba*) was beyond the scope of this paper.

The results obtained confirmed the usefulness

of hemisphere photographs in forest ecology and direct future research in:

- Establishing the optimal relation between hemispherical photographs taken at a certain height from the ground and the particular size of the surveyed forest plots, which is expected to be smaller than the one used here (490m^2), and case sensitive for different types of forests.
- Development of a semi-automated procedure to diminish a negative effect of sunlight in photographs that decrease their usage. This can be accomplished by developing the software that will set the appropriate threshold value for separation of image pixels into sky and non-sky classes based on formulas that will analyse each pixel.
- Further examine the relationship between canopy features and satellite images. This will enable one to conduct stratified sampling of hemisphere photographs that can be done under ideal light conditions, and to obtain information about the canopy characteristics for a bigger area using the satellite images, thus significantly reducing the costs of data gathering.

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