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DETERMINATION OF LEAF AREA INDEX (LAI) AT LEVEL II SAMPLE PLOTS ACCORDING ICP MANUAL

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Abstract: *The paper describes the methodology for determining LAI according to the ICP forest methodology, where hemispherical photographs were taken on a network of fixed points placed on the surfaces of three Sample plots Level II. Hemispherical photographs were processed by the Hemisfer software package. The data obtained by image processing were entered into the ICP Forests database. The obtained LAI values represent the response to the state of vegetation under the influence of different ecological conditions as well as anthropogenic influences, and will be the part of future annual monitoring at Sample plots of the Level II points*.

Key words ICP Forests, leaf area index, method Hemispherical photography, Hemisfer software.

ODREĐIVANJE INDEKSA LISNE POVRŠINE (LAI) NA BIOINDIKACIJSKIM TAČKAMA NIVOA II PREMA ICP PRIRUČNIKU

Izvod: *U radu je opisana metodologija za određivanje indeksa lisne površine prema ICP Forest metodologiji, po kojoj su snimljene hemisferne fotografije na mreži fiksnih tačaka postavljenih na površinama tri Bioindikacijske tačke Nivo-a II. Hemisferne*

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fotografije su obrađene programskim paketom Hemisfer softer. Podaci dobijeni obradom slika uneti su u bazu podataka ICP Forests. Dobijene LAI vrednosti pružaju odgovor o stanju vegetacije pod uticajem različitih ekoloških uslova, kao i antropogenih uticaja i biće deo budućeg godišnjeg monitoringa na Bioindikacijskim tačkama Nivoa II.

Ključne reči: ICP Forests, indeks lisne površine, metod hemisfernih fotografija, Hemisfer softver.

1. INTRODUCTION

The leaf area index (LAI) represents the ratio of leaf area and soil surface (Pince, 1993) and represents one of the most important characteristics of trees and forest stands (Fleck et al., 2020). LAI can be used to assess or predict the health status and invasion of pests (Pokorny and Stojnić, 2012; Wang et al., 2018) or plant productivity and biomass production potential (Pokorny and Stojnić, 2012; Scurlock et al., 1999), for monitoring the growth and changes of vegetation (Zhili et al., 2013), to drive the ecological system, crop growth and forest growth models (Myneni et al., 2002; Sonnentag et al., 2007).

Tree canopy is an extremely important parameter that interacts with global changes in the environment, and a reliable and objective assessment of leaf area index (LAI) is necessary for a better understanding of this relationship (Sidabras and Augustaitis, 2015).

LAI (measured in m^2/m^2) is defined as half the total leaf area of the forest canopy divided by the ground area below the canopy (Chen and Black, 1991).

Numerous direct, semi-direct and indirect methods have been developed to estimate the leaf area index (LAI), as well as subjective assessment methods (Jonckheere et al., 2004, Fleck et al., 2020).

For ICP Forests is very important that model applications know the maximum LAI that is reached during the vegetation period, since the annual development of leaves may be derived from this value (Fleck et al., 2020). The all methods that are applied in ICP Forest plots focus on measuring the maximum LAI (LAI_{max}) and had to prove that it is able to extract this quantity.

Several direct and indirect methods are used within ICP Forestry. Litterfall measurements and biomass harvesting are direct measurements. Even if direct measurement methods provide the most reliable LAI estimate, they are less commonly used because they are usually more laborious than other methods. Direct methods serve as a standard for validation of indirect and remote methods (Fleck et al., 2020).

Hemispherical photography, Plant Canopy Analyzer, SunScan Ceptometer and Airborne LiDAR are indirect measurements that are applied in ICP Forest plots. The essence of indirect methods is to quantify the penetration of light through the canopy and based on that to calculate amount of leaf area that allows the relationship between light above and below the canopy. The biggest limitation of these methods is the measurement at very low rates of light penetration. The leaf area index over 6 causes penetration rates of about 5% which poses a great challenge for optical instruments (Gower et al., 1999).

ICP Forests Programme (International Cooperative Programme on Forest Condition Monitoring) has been continuously performed in the Republic of Serbia since 2003 (Rakonjac et al., 2020). Institute of Forestry has been proclaimed as the National Focal Center of the Republic of Serbia by the Directorate of Forests – Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia.

The main subject of ICP Forests is the monitoring of anthropogenic (primarily air pollution) and abiotic factors on the condition and development of Europe's forest ecosystems (Gagić-Serdar et al., 2019). ICP Forests Programme has been performed on sample plots Level I and Level II through monitoring vitality and health condition. Level I include monitoring, observation and analyses of forest condition on sample plots in 16 x 16 km grid. Level II includes the intensive monitoring and deal with a greater number of input parameters of permanent observation plots (Stefanović et al., 2017). As part of the ICP Forests program the leaf area index will be monitored starting in 2021, on the Sample plots of Level II.

The application of LAI methods on a yearly basis is envisaged only within the framework of intensive monitoring of Level II, in order to obtain reliable information on the significant interannual variation of the leaf area shown by the forest canopy.

2. MATERIAL AND METHODS

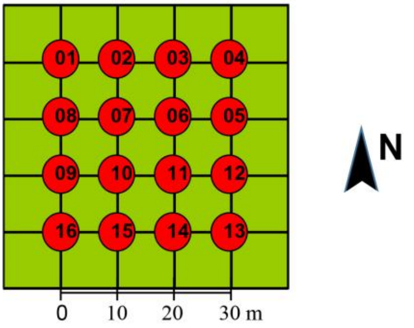
An indirect method Hemispherical photography (fish-eye photography), was used to determine the LAI at the Sample plots of Level II in Serbia.

Hemispherical photography (fish-eye photography) involves shooting photographs, registration, classification and calculation

The photographs were taken by looking upwards, with a wide-angle lens (180 °) quantifying the potential solar radiation at the point of observation. The photographs obtained in this way in the highest resolution contain the most comprehensive information in the corner. The photographs were taken in the early morning hours (conditions without direct light), avoiding the effect of reflection. The exposure was set automatically. During the photography, the zenith and azimuth (orientation) were determined. In order for the camera to be positioned at the top, towards the zenith, a self-leveling carrier was used, and a spirit level with three axes of leveling was attached to the camera itself. Photographs should be taken in the summer and winter. Summer photographs are taken during maximum foliation (from mid-July to mid-August), and winter after the leaves fall (before the buds burst in spring).

The classification of photographs is done automatically, determining which pixels of the image represent the visible and which the invisible part of the sky. An algorithm was used for the calculation, which is used to calculate the index of solar radiation and LAI.

During 2021, on the Sample plots of Level II at the following localities: Kopaonik, Crni vrh and Mokra Gora, a permanent grid for taking hemispherical photographs was set, which are used to obtain the leaf area index (LAI). A grid of points at a distance of 10 meters has been set up, within 50 m x 50 m, and photographs were taken from the inner 16 points. Such an arrangement of points is placed on a 30 m x 30 m grid, which covers an area of 0.25 ha. The illustration is shown at the Picture 1.



Picture 1. *Measurement design*

Positions for obtaining photographs were moved when they were close to or on an obstacle (tree, construction), by 5 times the diameter of the obstacle itself. All obstacles that were above the lens (branches, leaves) were removed. Positions for taking photographs are permanently marked on the field, with pegs and plastic tape.

To avoid ground vegetation, the camera is mounted on legs with a lens at a height of 1.3 m from the ground. The position of the camera is oriented so that the upper edge of the picture represents the north.

A Nikon D5000 camera and a Nikkor 10.5 mm full-frame (DX) wide-angle fisheye lens were used to take the photographs. A three-level spirit level is attached to the camera. All pictures were taken with delayed release (set to 10 seconds) to prevent camera shake or any movement of the camera.

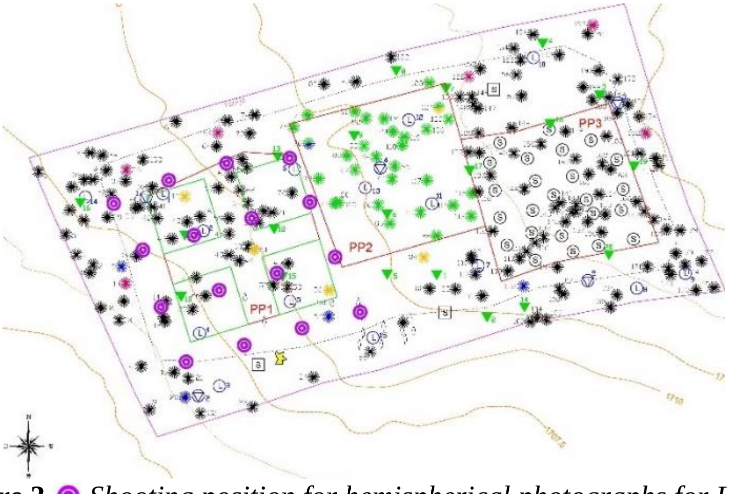
Picture 2. *Shooting hemispherical photography*

Taken photographs were analysed in Hemisfer software available from the web site: http://www.wsl.ch/dienstleistungen/software/hemisfer. At first automatic threshold determination were done and then LAI analysing. Because of very dense canopy the threshold for picture were done according to Ridler and Calvard (1978) method

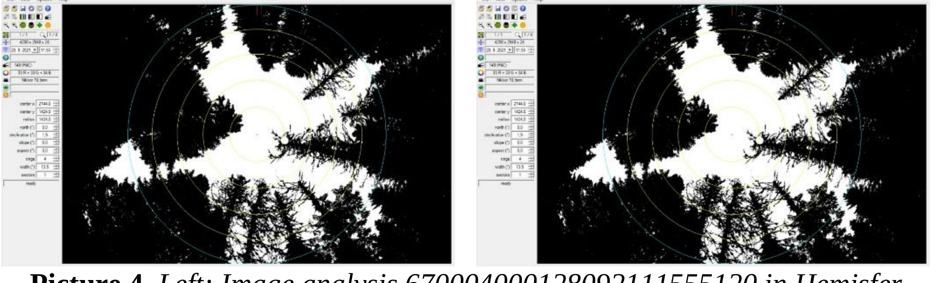
3. RESULTS AND DISCUSSION

The hemispherical photographs were analysed in 4 rings of 13.5°.

Kopaonik sample plot

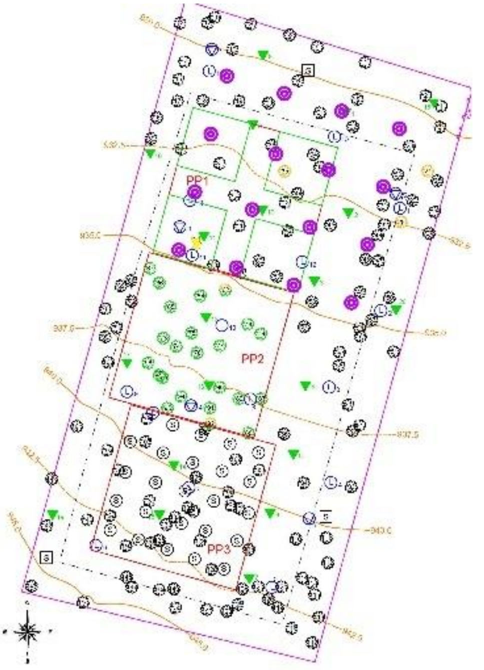


Picture 3. *Shooting position for hemispherical photographs for LAI on Kopaonik Sample plot*

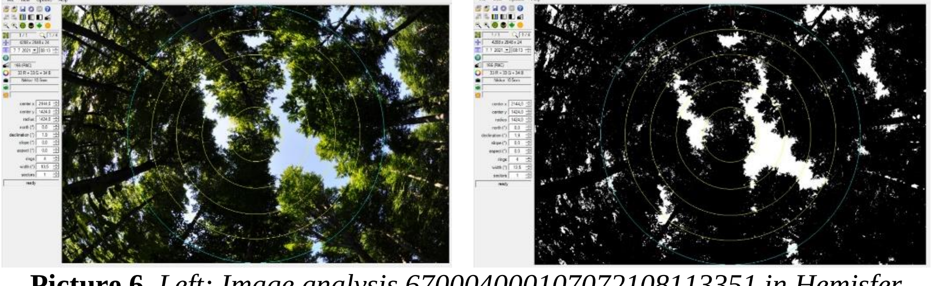


Picture 4. *Left: Image analysis 670004000128092111555120 in Hemisfer software*; *Right: The threshold for picture 670004000128092111555120 according to Ridler and Calvard (1978)*

Crni vrh sample plot

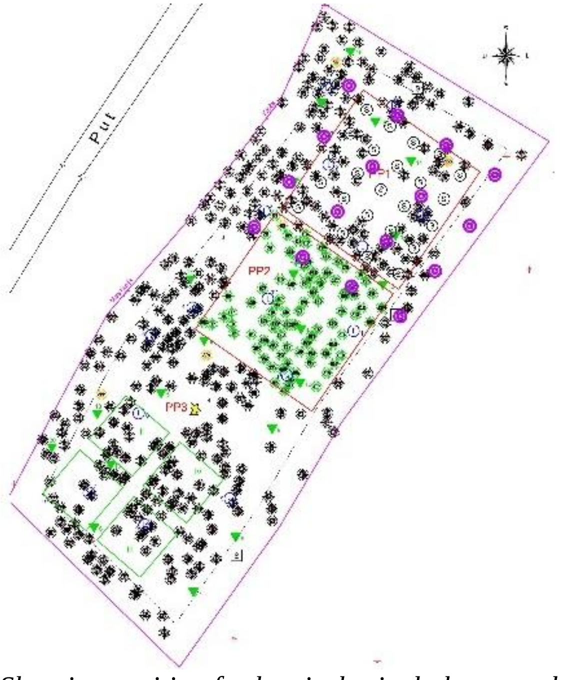


Picture 5. *Shooting position for hemispherical photographs for LAI on Crni vrh Sample plot*

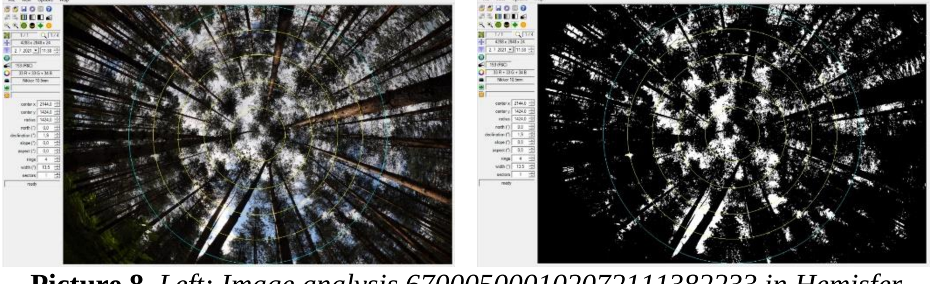


Picture 6. *Left: Image analysis 670004000107072108113351 in Hemisfer software*; *Right: The threshold for picture 670004000107072108113351 according to Ridler and Calvard (1978)*

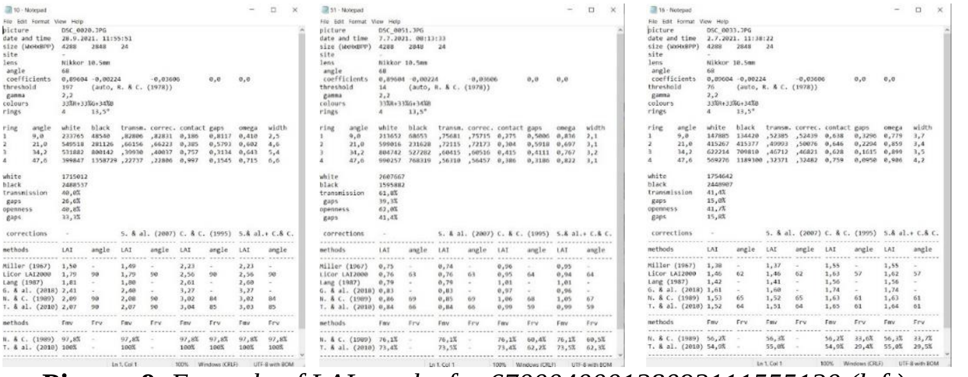
Mokra Gora sample plot



Picture 7. ◎ *Shooting position for hemispherical photographs for LAI on Mokra Gora Sample plot*



Picture 8. *Left: Image analysis 670005000102072111382233 in Hemisfer software; Right: The threshold for picture 670005000102072111382233 according to Ridler and Calvard (1978)*



```
10 - Notepad
File Edit Format View Help
picture          DSC_0020.JPG
date and time    28.9.2021. 11:55:51
size (WxHxBPP)   4288    2848    24
site             -
lens             Nikkor 10.5mm
 angle           60
 coefficients    0,89604 -0,00224        -0,03606        0,0     0,0
threshold        197     (auto, R. & C. (1978))
 gamma           2,2
colours          33%R+33%G+34%B
rings            4       13,5°

ring   angle  white   black   transm. correc. contact gaps   omega  width
1      9,0    233765  48540   ,82806  ,82831  0,186   0,8117 0,410  2,5
2      21,0   549518  281126  ,66156  ,66223  0,385   0,5793 0,602  4,6
3      34,2   531882  800142  ,39930  ,40037  0,757   0,3134 0,643  5,4
4      47,6   399847  1358729 ,22737  ,22806  0,997   0,1545 0,715  6,6

white            1715012
black            2488537
transmission     40,0%
 gaps            26,6%
openness         40,8%
 gaps            33,3%

 corrections     -               S. & al. (2007) C. & C. (1995) S.& al.+ C.& C.
---------------  --------------- --------------- -------------- ---------------
methods          LAI     angle   LAI     angle   LAI    angle   LAI     angle
---------------  ------- ------- ------- ------- ------ ------- ------- -------
Miller (1967)    1,50    -       1,49    -       2,23   -       2,23    -
LiCor LAI2000    1,79    90      1,79    90      2,56   90      2,56    90
Lang (1987)      1,81    -       1,80    -       2,61   -       2,60    -
G. & al. (2018)  2,41    -       2,40    -       3,27   -       3,27    -
N. & C. (1989)   2,09    90      2,08    90      3,02   84      3,02    84
T. & al. (2010)  2,07    90      2,07    90      3,04   85      3,03    85
---------------  --------------- --------------- -------------- ---------------
methods          Fmv     Frv     Fmv     Frv     Fmv    Frv     Fmv     Frv
---------------  ------- ------- ------- ------- ------ ------- ------- -------
N. & C. (1989)   97,8%   -       97,8%   -       97,8%  97,8%   97,8%   97,8%
T. & al. (2010)  100%    -       100%    -       100%   100%    100%    100%
---------------  --------------- --------------- -------------- ---------------
Ln 1, Col 1    100%    Windows (CRLF)    UTF-8 with BOM
```

```
51 - Notepad
File Edit Format View Help
picture          DSC_0051.JPG
date and time    7.7.2021. 08:13:33
size (WxHxBPP)   4288    2848    24
site             -
lens             Nikkor 10.5mm
 angle           60
 coefficients    0,89604 -0,00224        -0,03606        0,0     0,0
threshold        14      (auto, R. & C. (1978))
 gamma           2,2
colours          33%R+33%G+34%B
rings            4       13,5°

ring   angle  white   black   transm. correc. contact gaps   omega  width
1      9,0    213652  68653   ,75681  ,75715  0,275   0,5006 0,836  2,1
2      21,0   599016  231628  ,72115  ,72173  0,304   0,5918 0,697  3,1
3      34,2   804742  527282  ,60415  ,60516  0,415   0,4111 0,767  3,2
4      47,6   990257  768319  ,56310  ,56457  0,386   0,3186 0,822  3,1

white            2607667
black            1595882
transmission     61,8%
 gaps            39,3%
openness         62,0%
 gaps            41,4%

 corrections     -               S. & al. (2007) C. & C. (1995) S.& al.+ C.& C.
---------------  --------------- --------------- -------------- ---------------
methods          LAI     angle   LAI     angle   LAI    angle   LAI     angle
---------------  ------- ------- ------- ------- ------ ------- ------- -------
Miller (1967)    0,75    -       0,74    -       0,96   -       0,95    -
LiCor LAI2000    0,76    63      0,76    63      0,95   64      0,94    64
Lang (1987)      0,79    -       0,79    -       1,01   -       1,01    -
G. & al. (2018)  0,83    -       0,83    -       0,97   -       0,96    -
N. & C. (1989)   0,86    69      0,85    69      1,06   68      1,05    67
T. & al. (2010)  0,84    66      0,84    66      0,99   59      0,99    59
---------------  --------------- --------------- -------------- ---------------
methods          Fmv     Frv     Fmv     Frv     Fmv    Frv     Fmv     Frv
---------------  ------- ------- ------- ------- ------ ------- ------- -------
N. & C. (1989)   76,1%   -       76,1%   -       76,1%  60,4%   76,1%   60,5%
T. & al. (2010)  73,4%   -       73,5%   -       73,4%  62,2%   73,5%   62,3%
---------------  --------------- --------------- -------------- ---------------
Ln 1, Col 1    100%    Windows (CRLF)    UTF-8 with BOM
```

```
16 - Notepad
File Edit Format View Help
picture          DSC_0033.JPG
date and time    2.7.2021. 11:38:22
size (WxHxBPP)   4288    2848    24
site             -
lens             Nikkor 10.5mm
 angle           60
 coefficients    0,89604 -0,00224        -0,03606        0,0     0,0
threshold        76      (auto, R. & C. (1978))
 gamma           2,2
colours          33%R+33%G+34%B
rings            4       13,5°

ring   angle  white   black   transm. correc. contact gaps   omega  width
1      9,0    147885  134420  ,52385  ,52439  0,638   0,3296 0,779  3,7
2      21,0   415267  415377  ,49993  ,50076  0,646   0,2294 0,859  3,4
3      34,2   622214  709810  ,46712  ,46821  0,628   0,1615 0,890  3,5
4      47,6   569276  1189300 ,32371  ,32482  0,759   0,0950 0,986  4,2

white            1754642
black            2448907
transmission     41,4%
 gaps            15,0%
openness         41,7%
 gaps            15,8%

 corrections     -               S. & al. (2007) C. & C. (1995) S.& al.+ C.& C.
---------------  --------------- --------------- -------------- ---------------
methods          LAI     angle   LAI     angle   LAI    angle   LAI     angle
---------------  ------- ------- ------- ------- ------ ------- ------- -------
Miller (1967)    1,38    -       1,37    -       1,55   -       1,55    -
LiCor LAI2000    1,46    62      1,46    62      1,63   57      1,62    57
Lang (1987)      1,42    -       1,41    -       1,56   -       1,56    -
G. & al. (2018)  1,61    -       1,60    -       1,74   -       1,74    -
N. & C. (1989)   1,53    65      1,52    65      1,63   61      1,63    61
T. & al. (2010)  1,52    64      1,51    64      1,65   61      1,64    61
---------------  --------------- --------------- -------------- ---------------
methods          Fmv     Frv     Fmv     Frv     Fmv    Frv     Fmv     Frv
---------------  ------- ------- ------- ------- ------ ------- ------- -------
N. & C. (1989)   56,2%   -       56,3%   -       56,2%  33,6%   56,3%   33,7%
T. & al. (2010)  54,9%   -       55,0%   -       54,9%  29,4%   55,0%   29,5%
---------------  --------------- --------------- -------------- ---------------
Ln 1, Col 1    100%    Windows (CRLF)    UTF-8 with BOM
```

Picture 9. *Example of LAI results for 670004000128092111555120 (left), 670004000107072108113351 (middle), 670005000102072111382233 (right) files*

Picture 9. represent example of a results file for LAI, as obtained with the Hemisfer software. It contains general information about the picture (name, size), camera and lens. In addition, there is information about the angle, slope, threshold, gamma, channels (red, green and blue channels), rings, sectors (12 azimutal sectors, grouped by 3) and leaf angle (leaf angle limited between 35°-70°).

They are also shown results per ring (angle - average zenith angle in the ring, ignored, white, black, transmission - total gap fraction within the defined rings, transmission corrected after Schleppi et al. (2007), contact number based on the corrected transmission, gaps - proportion of large gaps estimated according to Chen and Cihlar (1995), omega - value of canopy clumping after Chen and Cihlar (1995) and width - foliar element width calculated for Chen and Cihlar (1995)), per ring and sector (azimuth, ignored, white, black, transmission and contact) and total (white - pixels (sky), black - pixels (canopy), ignored - pixels ignored, transmission - light transmission in 2D (azimutal equidistant projection of the hemisphere), openness - canopy openness in 3D, also called sky view factor (solid angles of the hemisphere) and gaps - of which large gaps).

The software outputs the LAI results according to Miller (1967), LiCor LAI2000, Lang (1987), Gonsamo et al. (2018), Norman and Campbell (1989) and Thimonier et al. (2010) with corrections: slope and non-linearity correction (Schleppi et al., 2007), clumping correction (Walter and Torquebiau, 2000), clumping correction (Lang and Xiang, 1986), clumping correction (Chen and Cihlar, 1995), robust regression (Gonsamo et al., 2018), ellipsoidal method (Norman and Campbell, 1989) and weighted ellipsoidal method (Thimonier et al., 2010). In addition, values of Fmv = transmission (total gap fraction) in vertical projection and Frv = fraction of large gaps in vertical projection are displayed by Norman and Campbell (1989) and Thimonier et al. (2010) method.

In Table 1. the basic data on the sample plots were shown and the LAI results recalculated in the Hemisfere software by the method of Thimonier et al., 2010, Non-linearity correction (Schleppi et al., 2007) and Canopy clumping (Chen and Cihlar, 1995).

The leaf area index is expressed in the LAI_{max} column, since the data refer to summer photographs when the plants are in maximum foliation, so the value of LAI is the maximum value of the index during one calendar year.

LAI_{max} values in summer measurement in Kopaonik Sample plot range from 0.3 to 6.58, in Crni vrh Sample plot range from 0.24 to 4.74 and in Mokra Gora Sample plot range from 0.56 to 4.21.

According to the data expressed in Table 1. the highest value of LAI is at point 8 on Sample plot Kopaonik 6.58, and the GAP fraction point is 2.43%. While the lowest value of LAI is 0.24 at point 7 on Sample plot Crni vrh, and the GAP is 72.70%. The highest mean value of LAI 2.55 is Sample plot on Kopaonik, and the lowest on Crni Vrh Sample plot 1.94 (mean value of LAI Mokra Gora Sample plot is 2.08).

Tabela 1. *Minimum and maximum values of LAI of individual images on Sample plots of the Level II in the vegetation period mean value*

Sample plot	Number of shots	Mean value LAI	Mean value GAP %	Minimum value LAI	GAP %	Maximum value LAI	GAP %
Kopaonik	16	2.55	37.04	0.30	58.40	6.58	2.43
Crni vrh	16	2.08	31.02	0.24	72.40	4.74	2.43
Mokra Gora	16	1.94	35.00	0.56	34.00	4.21	3.63

Leaf area index in response to various environmental impacts as well as the age of individuals in the tree layer have been subject of research for many authors (Balandier et al., 2006, Kantor et al., 2009, Bequet et al., 2012, Pokorny and Stojnić, 2012) so the data collected in this way from the permanent points on Sample plots Level II will be a useful for further research.

4. CONCLUSIONS

The results of the analysis of hemispherical photographs of the first survey on Sample plots of the Level II experimental fields indicate that the difference in the leaf area index exists in relation to the dominant woody vegetation. In coniferous species (Kopaonik and Mokra Gora), the average leaf area index with 16 measured hemispherical photographs is higher than in the area where the deciduous species (Crni vrh) is dominant. Also, the minimum value of the leaf surface index at certain points from which the photographs were taken is the lowest on the experimental surface Crni vrh, where the dominant species is deciduous. Bearing in mind that this is the first recording on Sample plots of the Level II, it can be stated that there are differences, but that only a long series of results obtained by recording in the coming period will allow correlating the values of leaf area index and density and age of vegetation of dominant species in the tree layer, as well as changes in climatic and other environmental factors that are part of the intensive monitoring of the condition at Sample plots of the Level II.

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DETERMINATION OF LEAF AREA INDEX (LAI) AT LEVEL II SAMPLE PLOTS ACCORDING ICP MANUAL

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Summary

When assessing the potential for photosynthetic activity and thus indirectly the vitality of vegetation in the studied area, one of the factors that is analysed is the leaf area index (LAI). LAI represents the total leaf area per unit of analysed area (m^2/m^2). As it is almost impossible to do this directly in the forest floor by collecting the assimilation organs and measuring them, in these cases this is done by various indirect methods. One of them is the analysis of hemispheric photographs with suitable software packages. The paper presents an analysis of hemispherical photographs made according to the ICP forestry methodology with the Hemispfer software package calculated by LAI. The obtained data were entered into the ICP Forests database with all relevant data on the quality and conditions that were when the photographs were taken. The results of the calculated LAI values will be used in further research on the impact of various ecological and anthropogenic factors on vegetation when a sufficient number of replications are performed during the summer and winter photographs in the following years.

ODREĐIVANJE INDEKSA LISNE POVRŠINE (LAI) NA BIOINDIKACIJSKIM TAČKAMA NIVOA II PREMA ICP PRIRUČNIKU

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Rezime

Kada se ocenjuje potencijal za fotosintetičku aktivnost, a time posredno i vitalnost vegetacije na istraživanom prostoru, jedan od faktora koji se uzima u obzir je indeks lisne povrsine (LAI - leaf area index). LAI predstavlja ukupnu površinu listova po jedinici analizirane površine (m^2/m^2). Kako je u šumskom sklopu gotovo nemoguće u spratu drveća to obaviti direktno sakupljanjem asimilacionih organa i njihovim premerom, to se u ovim slučajevima radi različitim indirektnim metodama. Jedna od njih je analiza hemisfernih fotografija pogodnim softverskim paketima. U radu je prikazana analiza hemisfernih fotografija načinjenih prema metodologiji ICP forestry sa softverskim paketom Hemisfer koji izračunava LAI. Dobijeni podaci su uneti u ICP Forests bazu podataka sa svim relevantnim podacima o kvalitetu i uslovima koji su bili kada su fotografije snimane. Rezultati izračunatih vrednosti LAI će se koristiti u daljim istraživanjima uticaja različitih ekoloških i antropogenih faktora na vegetaciju kada se izvrši dovoljan broj ponavljanja tokom letnjih i zimskih fotografisanja u narednim godinama.