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ESTIMATION OF LEAF AREA INDEX IN DWARF MOUNTAIN PINE (*PINUS MUGO* TURRA) USING HYPERSPECTRAL DATA

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ABSTRACT

The natural environment of the Tatras is one of the most diverse in Europe in terms of species richness and ecological value. This mountain range is well preserved and constitutes an important part of Europe's nature resources. Dwarf pine (*Pinus mugo* Turra) is the main component of the Tatras subalpine belt covering altitude between 1550 and 1800 m a.s.l. It is a very dynamic species, which expands rough terrain, covering systematically neighboring area and forming dense shrubs. The specific form of growth makes this community impenetrable. Monitoring and mapping of the subalpine region that used to be highly affected by the grazing is important for the understanding the natural processes determining the balance in the Tatras environment.

Leaf Area Index (LAI) is a key parameter controlling biophysical processes of the vegetation canopy. LAI can be measured using different methods such as optical ground-based instruments and optical imagery. Hyperspectral imagery obtained by DAIS and ROSIS spectrometers enable to distinguish genuine and absolute spectral differences that exist within the population of dwarf pine. The aim of this study is to investigate relationship between field measurements, information acquired from image and environment conditions in each (dwarf pine) test site.

Set of ground measurements describing biophysical characteristics of vegetation (Accumulated Photosynthetically Active Radiation - APAR, spectral properties) was also acquired.

Results of correlation between ground and imagery data show potentials for indicating intrapopulational variation in dwarf mountain pine community and its sources, which are basic information for ecological risk and long-term impacts assessment.

Keywords: hyperspectral images, ROSIS, DAIS, Tatras, *Pinus mugo* Turra

INTRODUCTION

Leaf Area Index (LAI) is dimensionless parameter defined as the one-sided or hemi-surface leaf area per ground surface unit (i) and is one of the most important variables controlling biophysical processes of the vegetation canopy such as vegetation photosynthesis and transpiration efficiency, evapotranspiration, productivity and vegetation condition. LAI has also influence on rainfall interception and carbon and nutrient cycle. LAI provides information about number of physical and biological characteristics of canopy through its high correlation with them (ii, iii, iv, v). Leaf area index is also the factor necessary to understand vegetation dynamics due to rapid response to climatic and environmental changes, which have already been observed in sensitive mountainous areas (vi, vii, viii).

Coniferous forests have been reported to achieve the highest values of LAI (ix), occasionally even LAI>15, although this might be according to definitions used and measurements methodologies (x).

LAI of vegetation is dependant on many factors e.g. site conditions, which in mountainous areas are connected mainly with altitude and relief; species composition; development stage (ix). Vertical canopy structure also influences LAI values because decides of light penetration ability through a forest canopy leaves, stems and branches, needles, cones and flowers (xi, xii, xiii).

The LAI of coniferous forests until now has been estimated relatively successfully in continuous stands of relatively high homogeneity (ii, iv, v, xiv, xv). In differentiated canopies, especially pines, there has been much uncertainty (xvi). In most studies vegetation indices (VI) based on red and near-infrared bands, used as input in the simple ratio (SR) or the normalized difference index (NDVI) have been applied to correlate with LAI (iii, xvii, xviii).

LAI can be measured in different ways by means of optical ground-based instruments and optical imagery. Direct measurements of LAI are relatively accurate, but on the other hand are time consuming, labour intensive, require destructive methods, limited to small areas and do not allow collecting continuous information. Non-invasive methods require application of indirect in-situ measurements or image based estimates (v, ix). Remote sensing provides way to obtain LAI over large areas, especially in high mountains, which are hard to access.

The project attempts to integrate airborne hyperspectral data with field LAI measurements.

Study area

The Tatra Mountains represent the highest part of the Carpathian Mountains range. The Tatras cover relatively small area of 785 km^2 and only 22.3% of their area is located within Poland (xix). The range consists of two main parts: the Western Tatras and the Eastern Tatras. The eastern part is further divided into the High Tatras and the Belianske Tatras. The division was established due to ranges composition. The West Tatras are built of calcareous rocks, less resistant to erosion, the High Tatras are composed mainly of igneous rocks (mostly granitoids) and the Belianske Tatras, situated entirely in Slovakia, is a limestone mountain-range (xx). The natural environment of the Tatras is one of the most diverse in Europe, in terms of species richness and landscape differentiation.

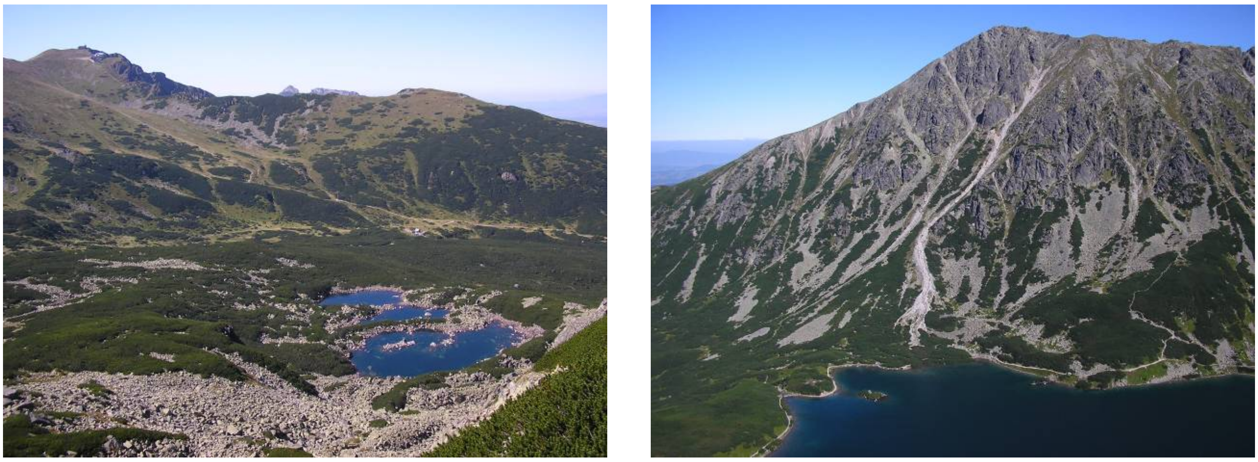

Figure 1:. The study site in the Gąsienicowa Valley.

The study site is located in the Gąsienicowa Valley (Figure 1). Dwarf pine (*Pinus mugo* Turra) is the main component of the Tatras subalpine belt covering slopes at altitude between 1550 and 1800 m a.s.l., where it constitutes its own plant association *Pinetum mughi carpaticum* (Figure 2). Depending on the geological substratum *Pinetum mughi carpaticum* association is divided into two subassociations: *Pinetum mughi carpaticum calcicolum*, which is rich in understory species and *Pinetum mughi carpaticum silicicolum* on siliceous rocks (xxi). The specific form of growth makes this community almost impenetrable for man. Monitoring and mapping of the subalpine region that used to be highly affected by the grazing is important for the understanding the natural processes determining the balance in the Tatras environment.

Figure 2: The Pinetum mugi carpaticum association in the Gasienicowa Valley (left) and dwarf mountain pine (Pinus mugo Turra) bush on the slopes of Kopa Magury Hill (right).

METHODS

Data acquisition

Test plots were chosen along the slope of Kopa Magury Hill. The information about leaf area index (LAI) was acquired using a LAI-2000 Plant Canopy Analyser (PCA) (xxii) during summer (July and August 2004) in conditions of diffuse solar radiation to avoid the direct sunlight on the sensor and to reduce the light scattering. In each plot there were taken two series of measurements, which effected in total ten averaged results in each place. Indirect LAI measurements are affected by range of external and internal factors, such as sky conditions, site conditions, development stage, amount of woody material, foliage clumping (xxiii).

Field measurements were carried out in a period of maximum effectiveness of life processes in mountain vegetation. Within each plot characteristics such as absorbed photosynthetically active radiation (APAR), canopy closure (percent coverage), needles condition (visually estimated on the basis of amount of needles affected by chlorosis), age of the oldest needles and composition of green understory were also acquired.

Image data and processing

DAIS and ROSIS were flown over the Tatras on the 4th of August 2002 around 10:30 a.m. local time. At this time of the day the sun elevation was 38° and sun azimuth was 145°. During the overflight 6 lines of DAIS and ROSIS images were acquired, of which 2 were taken additionally due to unfavourable atmospheric conditions. One line of ROSIS data was lost after some unexpected technical problems. Finally, 4 lines of DAIS and 3 lines of ROSIS data were used (Figure 3).

Each line of DAIS data covers an area of approximately 25 km^2 (2.5 km x 10 km), but because of large overlapping areas the images cover about 35 km^2 (3.5 km x 10 km) in total. A line of ROSIS data is smaller and covers an area of 5.6 km^2 (0.8 km x 7 km) approximately.

For the geometric correction of image data the PARGE (PARametric GEocoding) software was used. The software, developed at the University of Zurich specially for correcting airborne imaging spectrometer data, applies parametric geocoding using high precision flight parameters (like an exact position of the aircraft and its attitude angles) for every line. If used with a digital elevation model of high accuracy, PARGE can give very accurate results (xxiv).

DAIS data used in this study was geometrically corrected using all required parameters: GPS (Global Positioning System), INS (Inertial Navigation System), DEM (Digital Elevation Model) created from digitised contour lines, and several GCPs (Ground Control Points) of high accuracy. During this process the data was registered to the UTM coordinate system using the Nearest

Neighbour resampling method that retains original data values. The resulting pixel size is 3 metres, with a geometric accuracy within 2 pixels.

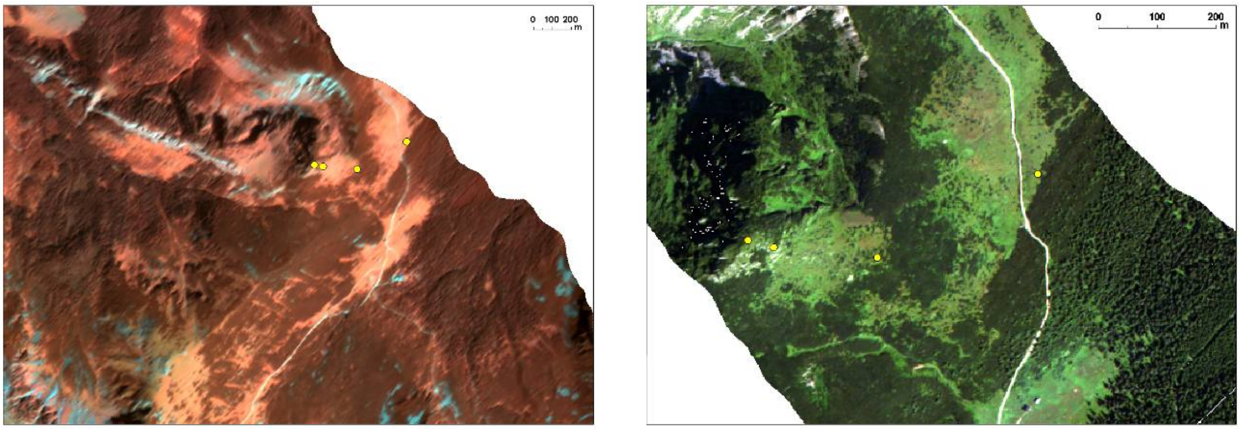

Figure 3: Samples of data used in the study with measurements plots overlaid. Left: DAIS image (false colour composition: R: 869 nm, G: 693 nm, B: 514 nm), Right: ROSIS data (colour composition: R: 690 nm, G: 558 nm, B: 478 nm)

Unfortunately, the procedure described above could not be applied to ROSIS data because of technical problems during data acquisition and missing parameters. Another approach had to be used employing polynomial transformation based on the large number of GCPs and the Digital Elevation Model. The data was also registered to UTM coordinate system using the same resampling method. Pixel size of the final image is 1 m. Since the geometric correction of ROSIS was not done by the authors themselves, the accuracy was not investigated thoroughly. Nevertheless, a comparison with DAIS and topographic data does not show any unacceptable geometric errors, which could prevent further analysis.

Atmospheric correction was performed on the DAIS data using ATCOR4 (ATmospheric CORrection) software, which includes a database of correction functions based on the MODTRAN4 radiative transfer code (xxv). During this process the data values were changed from radiance to reflectance, removing in this way the influence of the atmosphere on the data.

In the original data noisy bands were detected and removed in the part of middle infrared spectral region, which resulted in fact that only 40 bands of DAIS were qualified to further analysis (Table 1).

Table 1: Sensor characteristics (data used in the further analysis are greyed out).

	Spectral range [nm]	Number of bands	Spectral resolution	Spatial resolution [m]
DAIS				
1	400-1000	1-32 (32)	15-30 nm	3
2	1500-1800	33-40 (8)	45 nm	
3	2000-2500	41-72 (32)	20 nm	
	3000-5000	73 (1)	2 nm	
4	8000-12600	74-79 (6)	0.9 µm	
ROSIS				
	430-860	1-101	4 µm	1

Correlation of vegetation indices extracted from DAIS and ROSIS data

Spectral information was collected from the both datasets (DAIS and ROSIS) in a surrounding of each test plot. Ten pixels corresponding with dwarf pine patch, where LAI was acquired, were retrieved from the images. Reflectance values where averaged within visible (400-700 nm), near-infrared (700-1300 nm) and middle-infrared (after approximately 1300 nm) region. Obtained reflectance values were then used to compute vegetation indices: normalised difference vegetation index, simple ratio and reduced simple ration (only for the DAIS dataset) (Table 2). Vegetation indices were compared to results of LAI ground measurements.

Table 2. Applied vegetation indices.

Name	Abbreviation	Formula	Reference for description
Normalized difference index	NDVI	$\frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$	(xxvi)
Simple ratio	SR	$\frac{\rho_{NIR}}{\rho_{RED}}$	(xxvii)
Reduced simple ratio	RSR	$\frac{\rho_{NIR}}{\rho_{RED}} * \left(\frac{\rho_{MIR\max} - \rho_{MIR}}{\rho_{MIR\max} - \rho_{MIR\min}} \right)$	(xxviii)
Perpendicular vegetation index	PVI	$\frac{\rho_{NIR} - \rho_{RED} - b}{\sqrt{1+a^2}}$ $a = 0{,}9$ $b = 0{,}1$	(xxix)

RESULTS

Mean LAI values for the plots varied between 2,46 and 4,09 and were not distributed due to environmental gradients, which suggest that LAI is significantly affected by the local site condition. On the other hand fAPAR values increase with altitude above sea level (0.90 – 0.95). Only within the plot, which is located on the top of the hill, where was the lowest value (0.87), but this probably caused by the hardest conditions (exposition to al directions of wind) out of all other cases.

Vegetation indices showed strong positive correlations with LAI, nevertheless these results vary significantly between each plot due to applied index and value of correlation coefficient (Table 3). RSR (R^2_{max}=0.95) revealed better correlations than SR (R^2_{max}=0.87) and NDVI (R^2_{max}=0.87), which shows potentials for precise collecting of LAI for *Pinus mugo* Turra on the basis of remotely sensed data. Although obtained R^2 values are high, the difference in performing of varying indices for the certain plots, reveals that extrapolation of point measurements to the extensive areas must be carried out carefully.

Table 3. Correlation coefficients for vegetation indices compared to LAI (highest values are greyed).

Correlation coefficient Plot name	NDVI	SR	RSR	PVI
km_1	0.83	0.86	0.69	0.74
km_2a	0.87	0.88	0.95	0.85
km_2b	0.89	0.88	0.78	0.95
km_3	0.86	0.83	0.95	0.82
km_4	0.87	0.87	0.80	0.77

CONCLUSIONS

Averaging point measurements results to create rule suitable for calculating LAI for the whole image of interest, even, if they were designed to be representative for the entire study site, might be problematic. In each plot LAI is highly correlated to vegetation indices but structure of shrubs is influenced by many factors (altitude above sea level, exposition, slope, humidity etc.) that affect the site with different intensity. Moreover conifer canopies are formed specifically. They are grouped at the shoots, branch, whirls, and crown level (xxix) and these elements are not distributed randomly as is assumed by the measurement process performed by LAI-2000 (xxii). Clumping effect results in relatively large gap fraction in comparison to random canopies, to which conifers can not be classified. Clumping drives to underestimating LAI (in the case of dwarf pine gap fraction is differentiated among each bush), but on the other hand response form woody material can be to the certain extent compensate this phenomenon (xvi, xxiii).

Reflectance values registered in image pixels are strongly affected by needles chlorosis and other pigment stress caused by snow cover, wind, frost and fungi. Influence on reflectance is also associated with understory vegetation and amount of litter, which impacts the estimation of LAI on the basis of image derived reflectance values.

More attention should be paid to investigating certain band widths and formulation of spectral vegetation indices more suitable for obtaining LAI from large areas.

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References

i Chen J M & T A Black, 1992. Defining leaf-area index for non-flat leaves. Plant Cell And Environment, 15: 421-429.

ii Gong P, R Pu & J R Miller, 1995. Coniferous forest leaf area index estimation along the Oregon transect using compact airborne spectroscopic data. Photogrammetric Engineering & Remote Sensing, 61: 1109-1117.

iii Chen J M & J Cihlar, 1996. Retrieving leaf area index of boreal conifer forests using Landsat TM images. Remote Sensing of Environment, 55: 153-162.

iv Hu B, K Inannen & J R Miller, 2000. Retrieval of Leaf Area Index and Canopy Closure from CASI Data over the BOREAS Flux Tower Sites. Remote Sensing of Environment, 74: 255-274.

v Gong P, R Pu, G S Biging & M R Larrieu, 2003. Estimation of Forest Leaf Area Index Using Vegetation Indices Derived From Hyperion Hyperspectral Data. IEEE Transactions on Geoscience and Remote Sensing, 41: 1355-1362.

vi Davies A J, A J Jenkinson, J L Lawton, B Shorrocks & S Wood, 1998. Making mistakes when predicting shifts in species range in response to global warming. Nature, 391: 783-786.

vii Jiang L. & A Kulczycki, 2004. Competition, predation and species responses to environmental change. Oikos, 106: 217-224.

viii Klanderund K, 2005. Climate change effects on species interactions in alpine plant community. Journal of Ecology, 93: 127-137.

ix Jonckheere I, S Fleck, K Nackaerts, B Muys, P Coppin, M Weiss & F Baret, 2004. Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography. Agricultural and Forest Meteorology, 121: 19-35.

x Asner G P, J M O Scurlock & J A Hicke, 2003. Global synthesis of leaf area index observations: implications for ecological and remote sensing studies. Global Ecology and Biogeography, 12: 191-205.

xi Kucharik C J, J M Norman & S T Gower, 1998. Measurements of branch area und adjusting leaf area index indirect measurements. Agricultural and Forest Meteorology, 91: 69-88.

xii Chen J M, S G Leblanc, J R Miller, J Freemantle, S E Loechel, C L Walthall, K A Innanen & H P White, 1999. Compact airborne spectrographic imager (CASI) used for mapping biophysical parameters of boreal forests. Journal of Geophysical Research, 104: 27945-27959.

xiii Soudani K, Trautmann J & J-M N Walter, 2002. Leaf area index and canopy stratification in Scots pine stands. International Journal of Remote Sensing, 11: 95-111.

xiv Brown L, J M Chen, S G Leblanc & J,Cihlar, 2000. A Shortwave Infrared Modification to the Simple Ratio for LAI Retrieval in Boreal Forests: An Image and Model Analysis. Remote sensing of environment, 71: 16-25.

xv Fernandes R A, J M Chen, J R Miller & I G Rubinstein, 2004. Evaluating image-based estimates of leaf area index in boreal conifer stands over a range of scales using high-resolution CASI imagery. Remote Sensing of Environment, 89: 20-216.

xvi López-Serrano F R, T Landete-Castillejos, J Martìnez-Millán & A del Cerro-Barja, 2000. LAI estimation of natural pine forest using a non-standard sampling technique. Agricultural and Forest Meteorology, 101: 95-111.

xvii Fassnacht K S, S T Gower, M D MacKenzie, E V Nordheim & T M Lillesand, 1997. Estimating the Leaf Area Index of North Central Wisconsin Forests Using the Landsat Thematic Mapper. Remote Sensing of Environment, 61: 229-245.

xviii Turner D P, W B Cohen, R E Kennedy, K S Fassnacht & J M Briggs, 1999. Relationships between Leaf Area Index and Landsat TM Spectral Vegetation Indices across Three Temprate Zone Sites. Remote Sensing of Environment, 70: 52-68.

xix Mirek Z, 1996. Tatry i Tatrzański Park Narodowy. In: Przyroda Tatrzańskiego Parku Narodowego, edited by Z Mirek (Tatrzański Park Narodowy, Kraków – Zakopane), 17-26.

xx Klimaszewski M, 1988. Rzeźba Tatr Polskich (PWN, Warszawa) 667 pp.

xxi Piękoś-Mirkowa H & Z Mirek, 1996. Zbiorowiska roślinne. In: Przyroda Tatrzańskiego Parku Narodowego, edited by Z. Mirek. (Tatrzański Park Narodowy, Kraków – Zakopane) 237-274.

xxii LI-COR, 1992. LAI-2000 Plant Canopy Analyzer: Instruction Manual. (Lincoln, Nebraska, LI-COR, Inc.) 174 pp.

xxiii Stenberg P, 1996. Correcting LAI-2000 estimates for the clumping of needles in shoots of conifers. Agricultural and Forest Meteorology, 79: 1-8.

xxiv Schläpfer D & R Richter, 2002. Geo-atmospheric processing of airborne imaging spectrometry data. Part 1: parametric orthorectification. International Journal of Remote Sensing, 23: 2609-2630.

xxv Richter R & D Schläpfer, 2002. Geo-atmospheric processing of airborne imaging spectrometry data. Part 2: atmospheric/topographic correction. International Journal of Remote Sensing, 23: 2631-2649.

xxvi Pearson R L & L D Miller, 1972. Remote mapping of standing prairie, Pawnee National Grasslands, Colorado. In: Proceedings of the 8th International Symposium on Remote Sensing of Environment (ERIM International, Ann Arbor, MI). 1357-1381 pp.

xxvii Rouse J W, R H Haas & J A Schell, 1974. Monitoring the vernal advancement of retrogradiation of natural vegetation. (NASA/GSFC, type III, final report Greenbelt, MD: USA) 371 pp.

xxviii Richardson A J & C L Wiegand, 1977. Distinguishing vegetation from soil background information. Photogrammetric Engineering and Remote Sensing, 43: 1541-1552.

xxix Law B E, A Van Tuyl, A Cescatii & D D Baldocchi, 2001. Estimation of leaf area index in open-canopy ponderosa pine forests at different succesional stages and management regimes in Oregon. Agricultural and Forest Meteorology, 108: 1-14.