LEAF AREA INDEX OF FORESTS USING ALS, LANDSAT AND GROUND MEASUREMENTS IN MAGURA NATIONAL PARK (SE POLAND)

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ABSTRACT

Leaf Area Index (*LAI*) is one of the crucial characteristics describing forest canopy structure and is significant for biomass assessments which are important for characterizing forest ecosystems and rational management of wood resources. The main goal of this research was to estimate Leaf Area Index of forests located within borders of the Magura National Park (MNP) situated in the area of the Flysch Carpathians, Poland. Examined forest communities belong to two different vegetation layers in altitudinal zonation: foothills zone, up to 530 m a.s.l., and forest zone, located higher.

In situ ground indirect measurements of *LAI* were performed using a LAI-2000 Plant Canopy Analyzer. They were achieved within the scanned swath of the airborne laser scanning (ALS) with a density of 4 points/m^2 and Landsat images. Both Landsat images and ALS data were used to calculate the *LAI*. Field measurements were carried out between 23 and 29 August 2013 using two LAI-2000 Plant Canopy Analyzers. The campaign was organized just after the date of ALS data acquisition (22.08.2013). Several spectral vegetation indices (*NDVI*, *IPVI*, *MSR*, *GNDVI* among others) were tested in order to obtain the spatial distribution of *LAI* estimated on the basis of Landsat images as a comparison to *LAI* derived from ALS data. The *GNDVI* index was chosen as the best predictor of Leaf Area Index (R^2 = 0.705; r = 0.840). The results indicate that ALS offers an accurate tool for mapping leaf area index for forests at local or regional scale and that it is suitable for verification of *LAI* derived through passive optical remote sensing techniques over large areas. The results indicate that ALS-derived point density and Landsat vegetation indices are correlated and that ALS results present an acceptable accuracy of *LAI* estimations for all forest classes (R^2 = 0.5526). The comparison of ALS *LAI* and field measurements gave satisfactory results. The coefficient of determination for all forest classes in this case was equal to 0.456.

INTRODUCTION

Leaf Area Index is one of the most crucial structure characteristics describing forest canopy structure and it is closely related to evapotranspiration, biomass, photosynthesis, primary productivity, interception and many other processes with significant influence on the exchange of matter and energy between forests and the atmosphere. Accurate estimations of *LAI* are essential for biomass assessments which are necessary for the characterization of forest ecosystems and rational management of wood resources (1). Furthermore, net primary productivity (*NPP*), the rate at which an ecosystem accumulates biomass, is a good indicator of ecosystem health due to its reliance on a combination of basic ecosystem drivers: water, nutrient availability and sunlight (2). *LAI* is also widely used to model the carbon cycle in forests (3). Nowadays, the ability to measure *LAI* with high precision using remote sensing data becomes more common due to new possibilities for for-

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est planning and management (4,5). Studies on the use of ALS data in estimating *LAI* for forests were conducted by (6,7,1,8,9,10,11,12) among others. The aim of this study was to establish the relationships between *LAI* estimated on the basis of field measurements, satellite images and Airborne Laser Scanning (ALS) data.

METHODS

Study area

Research was conducted in south eastern Poland in the Magura National Park (with an area of 194.39 km² and a buffer zone of 226.97 km²). The MNP is placed in the central part of Low Beskid Mountains (21.5°E/49.6°N) in the macro-region Western Beskids and sub-province Outer Western Carpathians (13). 89.7% of the park lie in Podkarpacie Voivedship. Magura National Park is predominantly a forest. Forest and scrub communities cover about 93.79% of the Park, while natural and synanthropic herbaceous communities occupy only about 6.21% of its area (Figure 1).

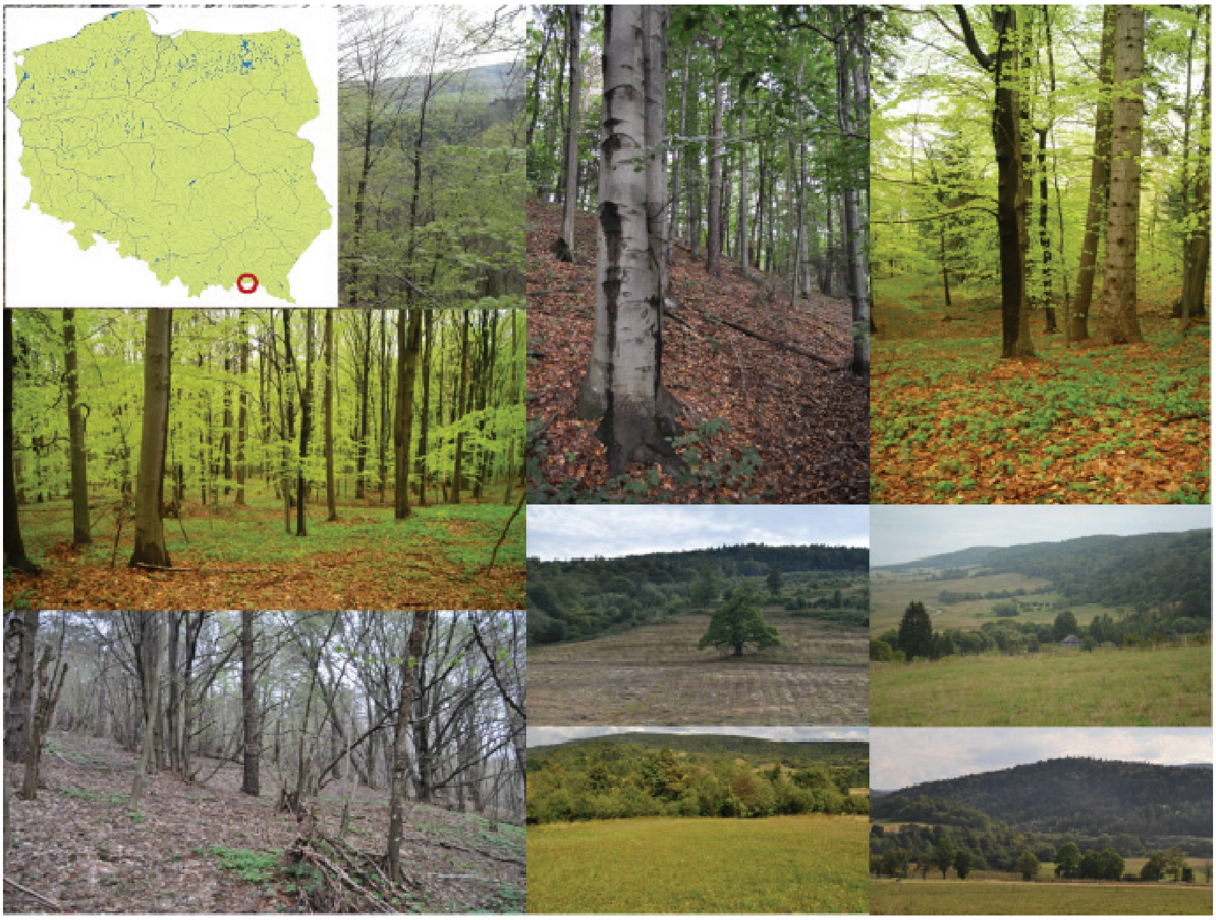

Figure 1: The research area and its typical vegetation cover (fot. Sylwia Szporak-Wasilewska).

Altitudinal diversity of vegetation within the study area is insignificant, as only two zones can be distinguished: the foothills and the forest zone between which the boundary runs at an altitude of 400 - 500 m a.s.l. on the slopes with northern exposure and at an altitude of 500 - 600 m a.s.l. for those with southern exposure (13).

In the MNP, 57 plant communities in the rank of the association or other equivalent units were distinguished (14). Forests and shrubs are represented by 16 natural communities: wet forests and riparian alluvial forests (swamp alder wood (*Ribo nigri Alnetum*, *Caltho – Alnetum*), fragments of sub-mountainous riverine carr *Carici remotae – Fraxinetum*, riverine carr *Alnetum incane* and community *Aegopodium podagrania – Fraxinus excelsior*); rare sycamore forests (*Sorbo-Aceretum*, *Phyllitido – Aceretum*, *Lunario-Aceretum*); rare linden – hornbeam forest (*Tilio – Carpinetum*); beechwoods (*Luzulo nemorosae – Fagetum, Dentario glandulosae – Fagetum*); fir forests (*Abieti – Piceteum montanum, Abies alba – Rubus hirtus*) and shrub communities (*Salicetum triandro – Viminalis*, *Myricaria germanice – Salix*, *Chaerophyllum hirsutum – Salix aurita*) (14).

Field measurements

Field measurements of the Leaf Area Index were carried out between 23 and 29 August 2013 using two LAI-2000 Plant Canopy Analyzers. The campaign was organized just after the date of ALS data acquisition (22.08.2013). Handheld GPS receivers Trimble Juno SC were used for localisation of the measurement points. The localisation accuracy after real-time EGNOS correction was expected to be 2 - 4 m. Measurements were performed at 108 locations covering the most typical vegetation found in the research area. In every location small circular plots were established (10 m radius) in which up to 10 measurements were carried out with LAI-2000.

LAI-2000 calculates *LAI* from radiation measurements (320 - 490 nm) above and below canopy made at five angles using a model of radiative transfer. Measurements above canopy were replaced by automatic radiation measurements performed at one-minute intervals on the clearings as close as possible to the measurement sites. Furthermore, all measurements were performed within scanned swath of the airborne laser scanning (ALS) and within the Landsat 7 and 8 scenes.

Satellite remote sensing data

Spatial distribution of Leaf Area Index was estimated on the basis of two satellite images with different spectral resolution: Landsat 7 ETM+ (08.08.2013) and Landsat 8 OLI (09.08.2013). The Landsat 7 image with data gaps resulting from SLC failure was corrected using tools developed in ArcGIS Model Builder (15). Both images were radiometrically and atmospherically corrected. The atmospheric correction was carried out applying the 6S radiative transfer model (Second Simulation of a Satellite Signal in the Solar Spectrum method) (16). All data sets were projected into the Polish PUWG-92 coordinate system. Several Spectral Vegetation Indices (*SVI*) were tested in order to obtain the spatial distribution of *LAI* from Landsat 7 ETM+ and 8 OLI in comparison with ALS-derived *LAI*: Normalized Difference Vegetation Index (*NDVI*) (17), Soil Adjusted Vegetation Index (*SAVI*) (18), Global Environment Monitoring Index (*GEMI*) (19), Simple Ratio (*SR*) (20), Moisture Stress Index (*MSI*) (21), Green *NDVI* (*GNDVI*) (22), Infrared Percentage Vegetation Index (*IPVI*) (23), Generalized Soil Adjusted Vegetation Index (*GESAVI*) (24), Normalized Difference Infrared Index (*NDII)* (25), *AVI* (26), *ARVI* (27). Eventually, the *GNDVI* index (22) was chosen among others to estimate the spatial distribution of LAI (see **Results**):

$$GNDVI = \frac{NIR - GREEN}{NIR + GREEN} \tag{1}$$

where NIR is the near infrared band (0.77 - 0.90 µm), GREEN is the green band (0.52 - 0.60 µm).

Additionally, a supervised classification was performed on the basis of a Landsat 8 image (resampled to 15 m spatial resolution) in order to distinguish forests in the research area. Classification allowed us to obtain 12 classes of land cover type among which 4 classes of forests were distinguished: forest, mixed forest, deciduous forest-northern exposure and deciduous forest-southern exposure.

Airborne Laser Scanning data

In order to estimate the Leaf Area Index with high accuracy airborne laser scanning (ALS) data were used with a scanning density of 4 points/m^2. Acquisitions were performed by MGGP Aero company, which is the leading provider of aerial photography and laser scanning data in Poland. The long-range airborne laser scanner Riegl LiteMapper 6800i.IGI[1] installed on board of a Cessna T206H NAV III aircraft was used, which is suited for aerial survey of complex terrain. Two separate scanning swaths were acquired on 22.08.2013: ~9 km × 1.5 km and ~5 km × 1.5 km (Figure 3). The ALS data allowed us to obtain the vertical distribution of tree canopies and provided highly

[1] RIEGL Laser Measurement Systems GmbH: Long-Range Airborne Laser Scanner for Full Waveform Analysis. LMS-Q680i product brochure from the Riegl website: www.riegl.com

accurate profiles of forest tree height and structure. The method of LAI estimation using ALS was developed and implemented by MGGP Aero. In a first step, the ALS data was processed in Terrasolid software dedicated to ALS point clouds data processing and then analysed in Teffs software. Based on the different densities of ALS beams reflected from the forest canopy, the single tree crowns were designated as polygons. Further analyses assumed that each single tree crown is represented by a hypothetical cuboid whose top and base are the crown polygons designated in a previous step divided into slices of 2 m. The basic unit of measurement (bin) was a cuboid 2 m high with a 1×1 m^2 base. Bins were calculated up to 48 m above ground; some bins were therefore "empty" with no points inside. To avoid division by zero those bins were assigned a very small value (0.000001). First, the number of laser point acquisitions in the given height range (bin) was calculated:

$$PointCount0To2 = Count \cdot Bin0To2$$
$$PointCount2To4 = Count \cdot Bin2To4$$
etc.

[Laser point acquisition counts (from 0 to 2 m) = Overall point count·percentage in bin (from 0 to 2 m), etc.]

To obtain laser point acquisition counts in each bin the overall point count was taken and multiplied by the percentage of points contained in the given bin. This was repeated for every bin created. Next, partial sums were calculated by adding consecutive ranges to the sum of all previous ones.

$$Sum0To2 = PointCount0To2;$$
$$Sum0To4 = PointCount2To4 + Sum0To2;$$
$$Sum0To6 = PointCount4To6 + Sum2To4$$
etc.

Then the *LAI* for each bin was calculated as follows:

$$LAI0To2 = PointCount0To2 \;/\; Sum0To2$$
$$LAI2To4 = PointCount2To4 \;/\; Sum0To4,$$
$$LAI4To6 = PointCount4To6 \;/\; Sum0To6$$
etc.

LAI in each bin is the quotient of point count in the given bin and sum of points for this bin. The overall *LAI* value was calculated as a sum of *LAI* values from all bins:

$$LAISum = LAI0To2 + LAI2To4 + LAI4To6 + ...$$

RESULTS

The relationship between spectral vegetation indices derived from Landsat spectral bands and all *LAI* field measurements (including forests and non-forest points) showed that the SVIs significantly correlated with *LAI*. Field measurements for forests of *MNP* were

- *ARVI* - Atmospherically Resistant Vegetation Index (R^2 = 0.661; r = 0.813)
- *NDVI* - Normalized Difference Vegetation Index (R^2 = 0.673; r = 0.820)
- *IPVI* - Infrared Percentage Vegetation Index (R^2 = 0.673; r = 0.820)
- *MSR* - Modified Simple Ratio (R^2 = 0.685; r = 0.828)
- *NDII*5 and *NDII*7-Infrared Indices (R^2 = 0.684; r = 0.827, R^2 = 0.689; r = 0.830 respectively)
- *GNDVI*-Green *NDVI* (R^2 = 0.705; r = 0.840) for Landsat 7
- *NDII*5 (R^2 = 0.626; r = 0.790) and *MSI* (R^2 = 0.610, r = 0.780) for Landsat 8.

The determination and correlation coefficients for other indices were lower than 0.5 and were excluded from further analysis. Finally, the *GNDVI* index (22) was chosen as the best predictor of Leaf Area Index. The linear regression model presented in Figure 2 was used to estimate spatial distribution of *LAI* on the basis of Landsat 7 image:

$$LAI = 21.828 \cdot GNDVI - 12.318 \quad (2)$$

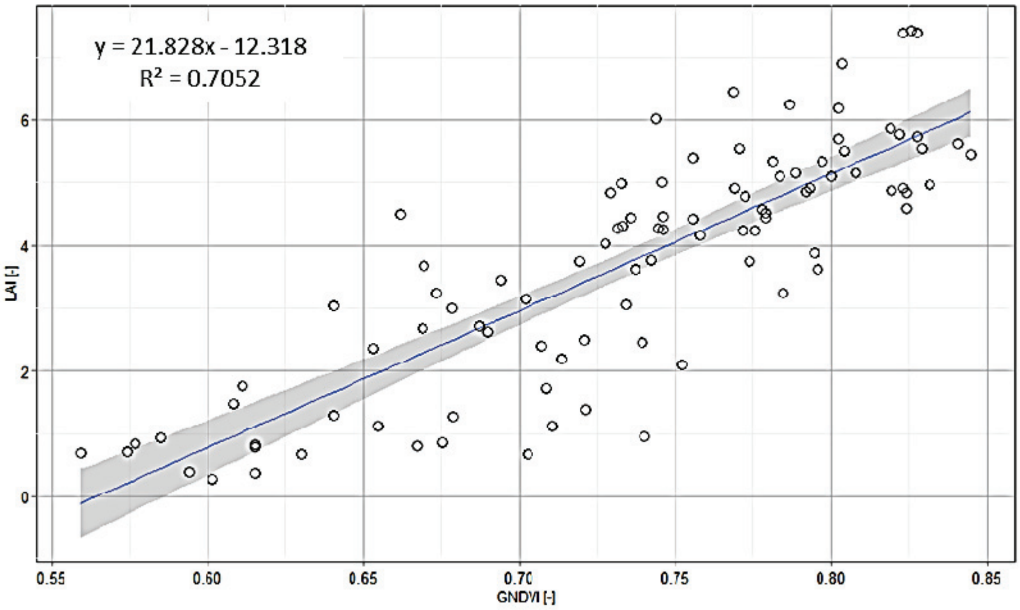

Figure 2: LAI developed on the basis of field measurements and GNDVI and linear regression model with a 95% confidence interval.

The *LAI* estimates based on *GNDVI* gave acceptable results for designated forest classes (R^2=0.536; r=0.732 for all forest classes, R^2=0.524; r=0.724 for mixed forests and R^2=0.618; r=0.786 for deciduous forests). The mean value for all forest classes was 5.63 m^2/m^2: 5.52 for mixed forests, 5.56 for deciduous forests, 5.67 for deciduous forests with northern exposure and 5.77 for deciduous forests with southern exposure. The results indicated also suitability of several other vegetation indices in estimations of *LAI* for forests using Landsat.

The ALS data allowed us to obtain the spatial distribution of *LAI* with high spatial resolution (Figure 3). Resulting *LAI* values were compared to *LAI* values estimated from *GNDVI* index and to field measurements. The mean value of *LAI* estimated on the basis of ALS data for all forest classes was 4.36 m^2/m^2: 4.31 for mixed forests, 4.40 for deciduous forests, 4.37 for deciduous forests - northern exposure, and 4.34 for deciduous forests - southern exposure. Further analysis was conducted on ALS *LAI* values and *GNDVI LAI* values within 4 land cover classes representing different types of forests. The results are shown in Table 1.

Table 1. Results for ALS LAI and GNDVI LAI comparison for chosen forest classes designated after Landsat 8 supervised classification.

Forest type class	R^2
All forest classes	0.5526
mixed forest	0.4793
deciduous forest	0.5464
deciduous forest - northern exposure	0.6018
deciduous forest - southern exposure	0.6538

The comparison of ALS *LAI* and *GNDVI LAI* gave acceptable results, but showed that some method improvement is necessary in order to estimate LAI from ALS data more precisely. However, it is difficult to compare different methods of data acquisition: laser and optical remote sensing. ALS *LAI* values gave sufficient results as compared with *LAI* field measurements. The coefficient of determination for all forest classes was 0.456 and 0.475 for mixed forest classes. Better results were obtained for deciduous forests for which R^2 was 0.557.

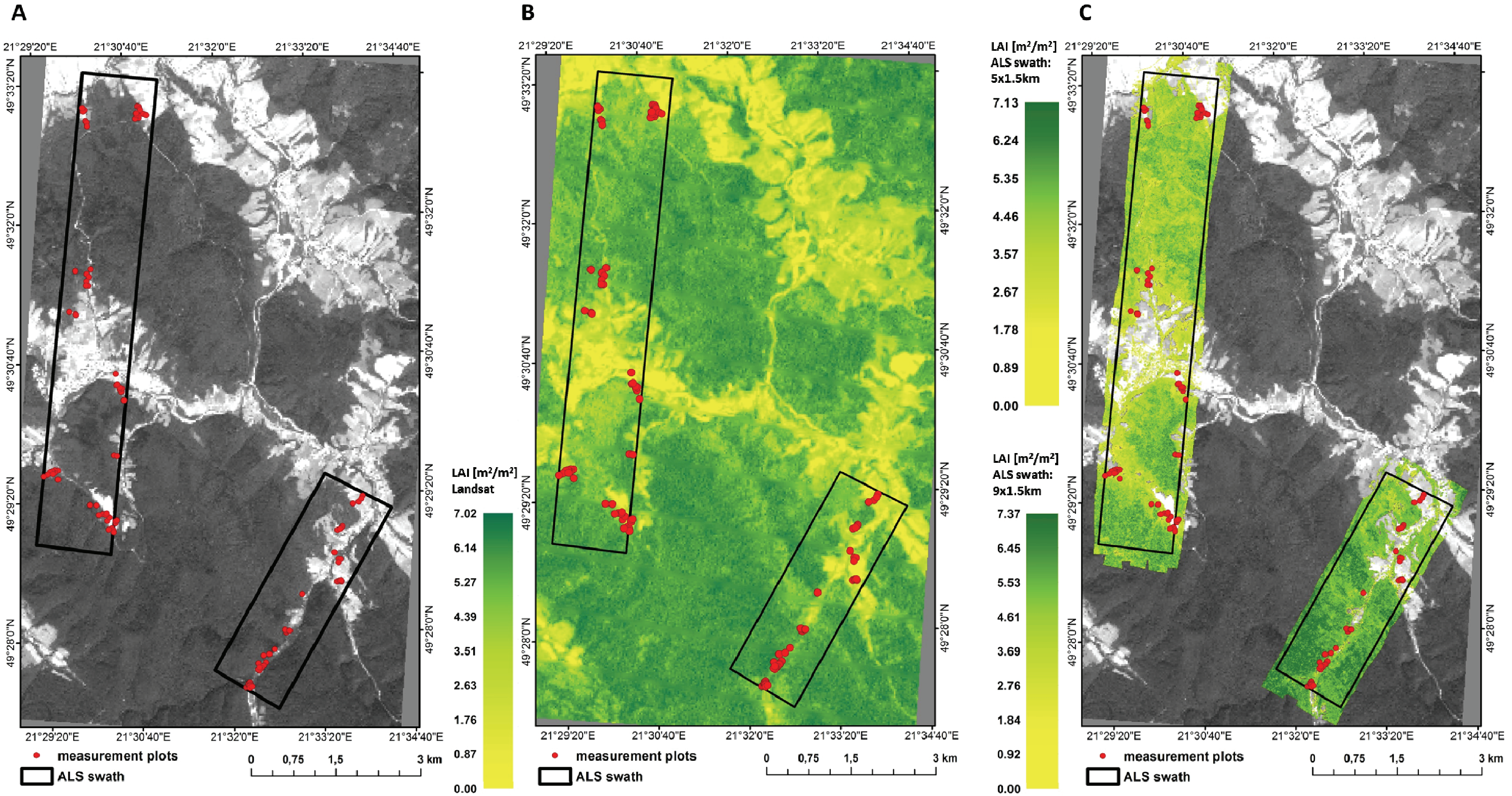

Figure 3: Location of the field measurements and scanned ALS swaths (A), LAI based on Landsat 7 GNDVI index (B), LAI derived from the ALS data (C).

CONCLUSIONS

Landsat imagery is a suitable data source in forest mapping due to its global coverage, no costs, very long temporal record and high spectral resolution. Many vegetation indices developed for Landsat 5 and 7 are suitable for *LAI* estimations in forests which was also proved in this study. Unfortunately, the same vegetation indices calculated for Landsat 8 did not give satisfactory results as only one index was significantly correlated with *LAI* (*NDII*5 with r = 0.790). For all other tested indices the correlations were below 0.4 showing the necessity of developing new SVIs for *LAI* estimation purposes using OLI sensor. As compared to Landsat images, ALS data can better represent the three-dimensional structure of forests due to Landsat's limited sensitivity to vertical and below-canopy vegetation structures (28). The model derived from high point density ALS data in the Magura National Park (developed only for forest) seems to offer a reliable method of estimating *LAI* at high resolution when compared to *LAI* estimated on the basis of Landsat images, which is suitable for verification of *LAI* derived through passive optical remote sensing techniques over large areas. The comparison of *ALS LAI* and field measurements gave satisfactory results. Nevertheless, some method improvement is suggested comprising better planning of field measurements, further development of the MGGP ALS *LAI* method and development of new SVIs for Landsat 8 OLI images.

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