

INTEGRATION OF REMOTE SENSING DATA INTO FOREST INVENTORY IN CLOSE-TO-NATURE FORESTS: AN INITIAL CASE STUDY IN SMOLNÍCKA OSADA, SLOVAKIA

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ABSTRACT

The initial case study concerns the first assessment of possibilities of integrating remote sensing into forest inventory in Slovak close-to-nature forests. Aerial images and airborne laser scanning data were used to estimate forest stand characteristics, such as the number of trees, mean tree height, mean tree diameter, and growing stock. eCognition software for tree species classification and reFLex software for individual tree detection was used. The accuracy of the assessment was conducted in the ProSilva object Smolnícka Osada (Eastern Slovakia, Central Europe), which has been under selective management for more than 60 years. The ALS data were obtained with a Leica RCD30 scanner from an average height of 1,034 m with a point density of 4 echoes per m². The ground reference data contained the measured positions and dimensions of 924 trees in 35 plots distributed across the region. It was found that the difference between the remote-based results and ground data was -50% for the number of trees, 8% for mean height and diameter, and -28% for growing stock.

KEYWORDS

Uneven-aged forests; Object-oriented classification; Individual tree detection approach; Airborne laser scanning.

INTRODUCTION

Close-to-natural forests are characterised by heterogeneous tree heights and diameters, as well as uneven tree species composition. Rich structure makes these ecosystems more stable from ecological as well as static viewpoints: they are resistant to damaging agents and destructive factors of the environment (1). However, there are some obstacles in the way of broader use of close-to-nature forestry, namely the absence of effective forest management practices, including special inventory procedures for such type of forests.

Applied methods of the remote sensing (RS) based on the combination of aerial imaging and airborne laser scanning (ALS) represent a perspective possibility of investigating the state of forests, even those with a complex structure. The recognition of the positive effects of stand-structure diversity on the quality of most ecosystem services has also underscored the importance of new RS approaches to stand-structure mapping. This fact is supported by a number of scientific studies (e.g., (2)). Present-day research is mainly focused on automation of large-scale inventories of forest resources. There are two different approaches to the ALS data-based acquisition of respective information. The first, Area-Based Approach (ABA) uses the statistic correlation between field-measured variables and metrics of ALS data. The second Individual-Tree Detection approach (ITD) is based on the detection of single trees and the extraction or estimation of their attributes. Actual knowledge suggests that the accuracy of ITD or ABA ranged between i) 32-89% for individual tree detection (3,4), ii) 9-33% for tree heights (5,6), iii) 16-46% for tree diameters (7,8), and iv) 10-42% for growing stock (9,10).

The paper's objective is the pilot evaluation of the possibilities of RS application to the inventory of heterogeneous uneven-aged forests in the surrounding of Smolnícka Osada (Eastern Slovakia).

METHODS

Study area description

The case study was carried out on the territory of the Pro Silva Demo Site Smolnícka Osada (48°44'N, 20°46'E), where close-to-nature forest management has been applied for more than 60 years. For the purpose of this paper, 35 reference plots (RP) with a total area of 1.95 ha were examined. The whole forested area of the Demo Site is 2,128 ha (Figure 1).

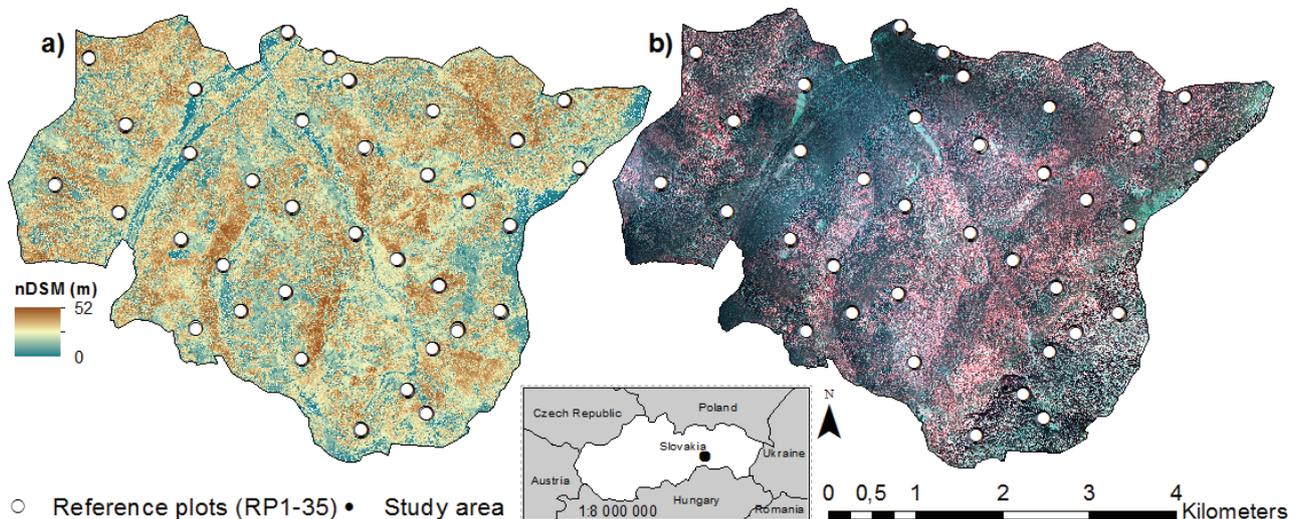


Figure 1: Study area: (a) Normalised digital surface model; (b) Colour-infrared aerial photograph.

Remote sensing data

Aerial imaging and scanning was carried out simultaneously in September 2014 using the carrier Cessna TU206F with an average flight height of 1,034 m.

The multispectral aerial images with a resolution of 9000×6732 px were acquired using a Leica RCD30 camera. Point clouds were acquired using a Leica ALS 70-CM airborne laser scanner at 228 kHz pulse rate frequency with an angle of 49° (FOV). The laser data had an average density of laser hits of 4.3 points per m^2 .

Ground reference data

On selected 35 RPs, from June to November 2014, 924 trees were measured using traditional terrestrial equipment (i.e., calliper, altimeter). However, only trees higher than 5 m were taken into account for the accuracy assessment in the study, which reduced the number of trees in the file to 910.

There was a dominance of conifers on RPs. Based on the tree species proportion in the growing stock, Silver Fir dominates with 49%, Scots Pine reaches with 10% and Norway spruce with 7%. Broadleaves were represented mainly by European beech (30%). The rest consisted of Larch and so-called noble hardwoods. The distribution of tree heights broken down into the groups of conifers and broadleaves is shown in Figure 2. Without this breakdown, mean diameter reached 28.5 cm and mean height 23.7 m. The average volume of a single tree was $0.84 m^3$ and total growing stock on all RPs was $774 m^3$ (under bark).

Remote-based forest inventory

Number of trees and tree height

The tree number and tree heights were detected, based on the reFLex algorithm, which includes several tree allometry rules on permissible tree heights and crown dimensions in order to increase the likelihood that real trees are detected (11,12,13).

The input file is a classified point cloud that contains ground and vegetation classes. The initial procedures are applied to divide the points into 3-dimensional regular tiles, calculate the absolute

height above ground for each point and reduce the number of points in the input file by applying a minimum tree height threshold. These operations produce a point cloud that is further used for an iterative search for treetops and tree crowns as well as for estimation of tree heights. Finally, the outputs of all procedures are exported to point and polygon vector files in the ESRI shp format. The mean height represents an average value of tree heights.

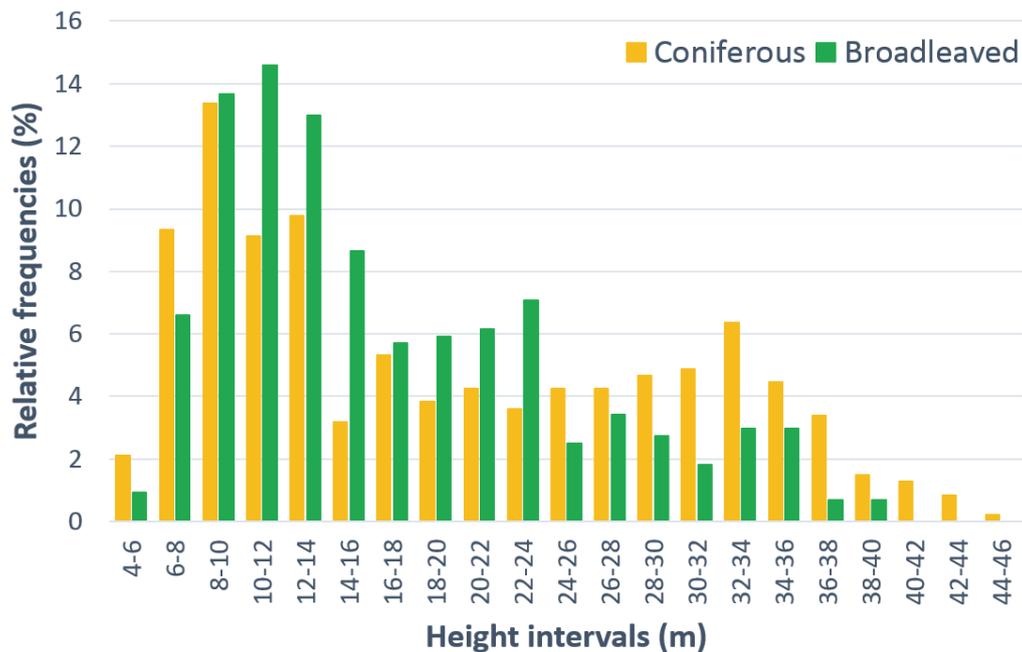


Figure 2: Relative frequencies of coniferous and broadleaved trees measured on the ground within the height intervals.

Tree species composition

Tree species composition was determined at the level of identified objects classification into two classes - broadleaved and coniferous trees. For this purpose, the object-oriented classification of CIR images with spatial resolution of 0.5 m was used. This was processed with the eCognition Developer 8 software.

At first a multiresolution segmentation was implemented on the orthophoto images. Emphasis was placed more on colour than on the object shape (14). For image classification, the controlled classification method was applied using the training classes, i.e. a pre-defined mask. The Standard Nearest Neighbour (SNN) classifier was applied in the classification process. The result was a raster layer representing tree classes: broadleaved trees, coniferous trees and shadow. At the end, one of the classification classes was assigned to each delineated tree crown using the reFLex algorithm and zonal statistics functions. The result was a vector layer representing the tree crowns, with their assigned attribute: broadleaved or coniferous tree.

Tree diameter

The diameter of each tree was calculated via regression-modelling principles, based on the assumingly high correlation between tree diameter and height.

Therefore, in the beginning, the one-dimensional non-linear regression models for both groups, broadleaves ($n=443$) and conifers ($n=481$), were created using the complete set of field data ($n=924$). In this way, regression functions describe conditions within the whole study area. In the following, these were used to estimate the diameters of trees that were identified by the algorithm reFLex, when diameters were have been estimated based on RS-measured heights. Mean diameter was calculated as an average of the estimated diameters of each particular tree.

Tree volume

In the calculation of the volume of each particular tree, an algorithm (15) based on the principle of two-argument volume functions (16) was used. The volume of each particular tree was estimated using the relation between tree height and diameter.

In this study, the tree species were not classified, just the group of conifers or broadleaves was used instead. For the volume calculation, the functions of the tree species with the highest proportion in the respective growing stock were therefore used as a compromise. For the broadleaves, the “beech function” was used, for conifers it was “fir function”. Total growing stock was counted as a sum of particular tree volumes.

Accuracy assessment

Accuracy assessment was carried out via comparison of field data (GR) and the results obtained from remote sensing (RS). The RS-data file contained all trees identified by the reFLex algorithm, the crown centroid of which was located within the borders of the respective RP.

RESULTS

In total, 454 trees were detected using the reFLex algorithm. Compared to the 910 reference trees, this represents an extraction rate of approximately 50%. It means that 456 trees were not identified (Figure 3).

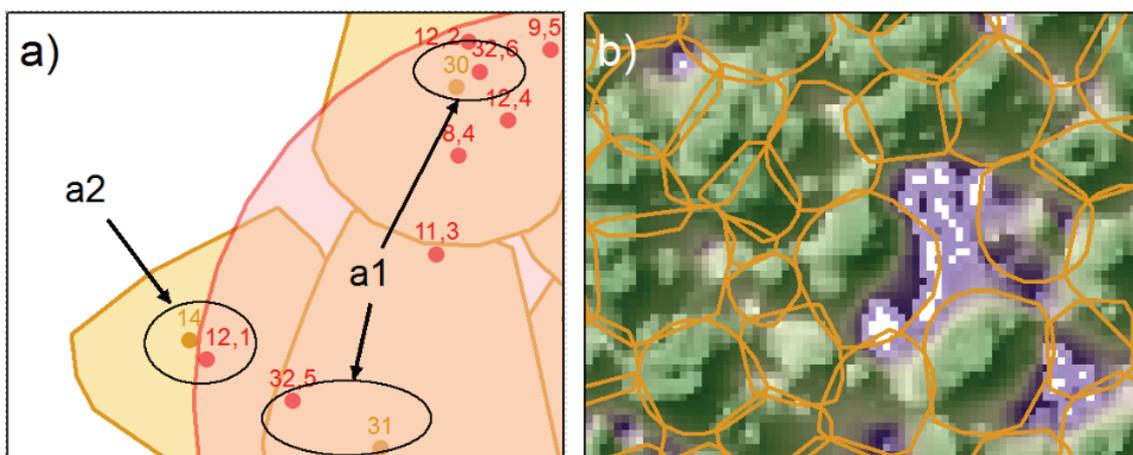


Figure 3: Treetops detected, tree crowns delineated, and tree heights evaluated using reFLex algorithm (orange points, polygons, and numbers) and reference treetops, tree heights, and plot (red points, polygon, and numbers). (a) Detail of treetops matching: a1 – Detected and matched treetops are within the reference plot; a2 – Detected and matched treetop is out of the reference plot; (b) Delineated tree crowns with the nDSM overlay.

The average height of the trees detected via laser scanning was 26 m. Compared to the reference data ($h=24$ m), the relative difference was 8%. The distribution of tree heights within height classes is shown in Figure 4. From the figure, it is obvious that the use of reFLex algorithms leads to an overestimation of the number of trees in higher height classes and to an underestimation in lower height classes.

Tree species classification to the group of either conifers or broadleaved trees was, as expected, strongly determined by their vertical position and achieved accuracy of the classification (Figure 5). Approximately 80% of all coniferous trees were identified with a classification accuracy of 88%. Quite contrary, as many as 81% of broadleaved trees were not identified. That was caused by their social position (broadleaves are mainly under the main canopy) and particularly by the low, only 34%, accuracy of classification (producer’s accuracy). Therefore, broadleaved trees were not visible in RS records or, respectively, they were shaded, which influenced the spectral values of respective pixels.

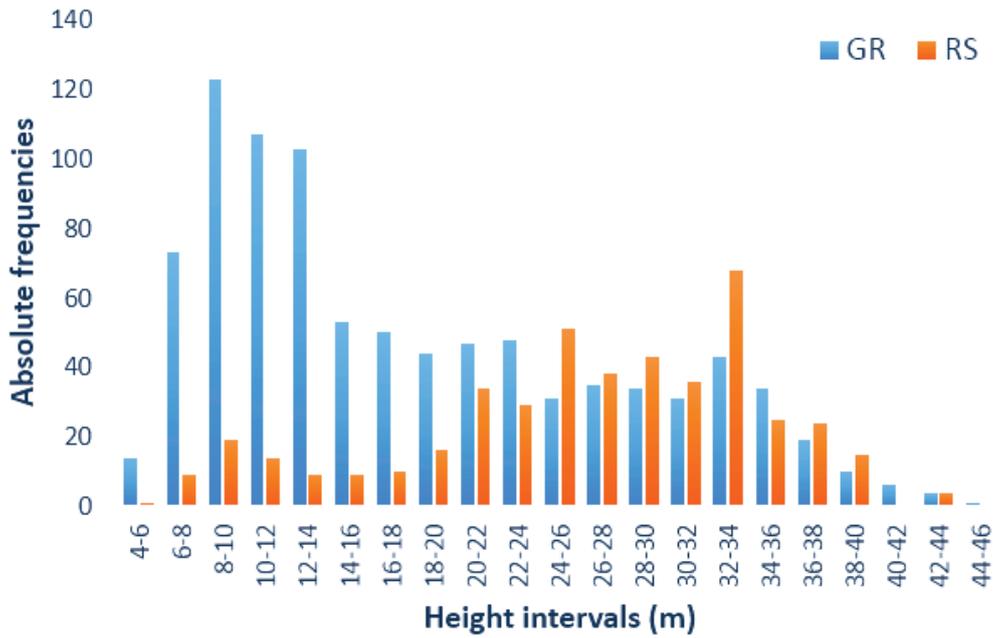


Figure 4: Absolute frequencies of measured (GR) and detected (RS) trees within the height intervals.

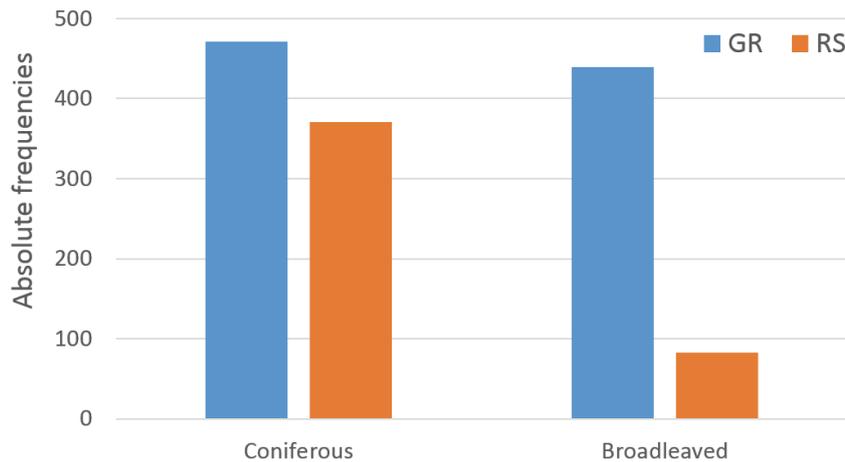


Figure 5: Absolute frequencies of measured (GR) and detected (RS) trees divided to coniferous and broadleaved trees.

Tree diameters were deduced from constructed regression models, and thus the accuracy depends not only on the accuracy of tree height identification, but also on the accuracy of the constructed regression function. The relative mean error of the used regression functions reached 26.4% on average. The resultant difference between the RS-identified average diameter and mean diameter of measured trees was 8%. The distribution of the tree counts within diameter classes is shown in Figure 6.

Growing stock was calculated from the directly measured characteristics (the number and height of trees, group of tree species) and the derived tree diameters was 554.6 m³. Thus, the relative difference between this figure and the actual growing stock (773.9 m³) was -28%. The distribution of the tree counts within volume classes is shown in Figure 7.

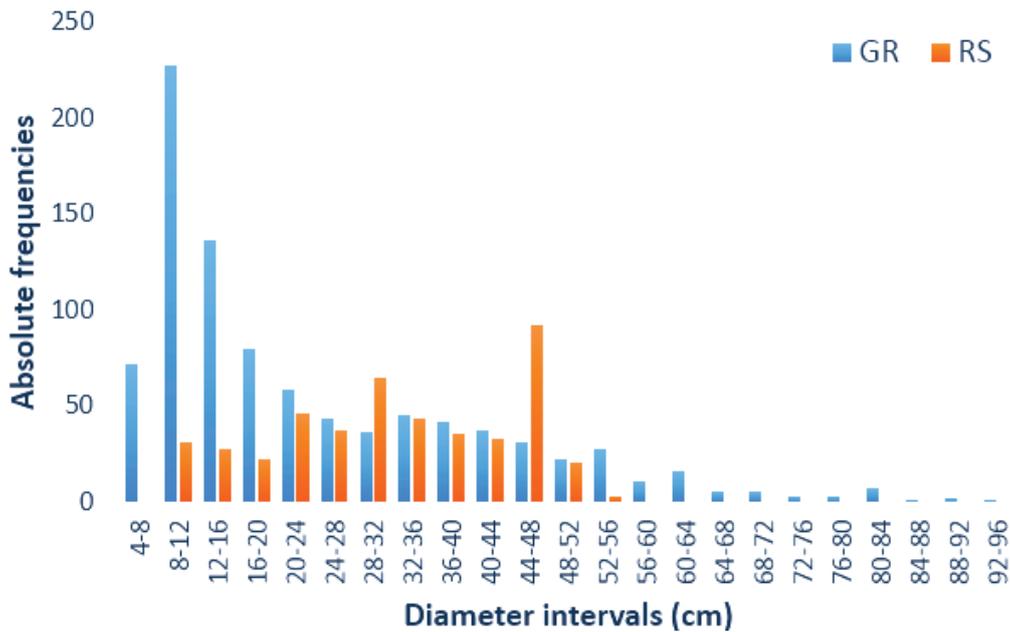


Figure 6: Absolute frequencies of measured (GR) and detected (RS) trees within the diameter intervals.

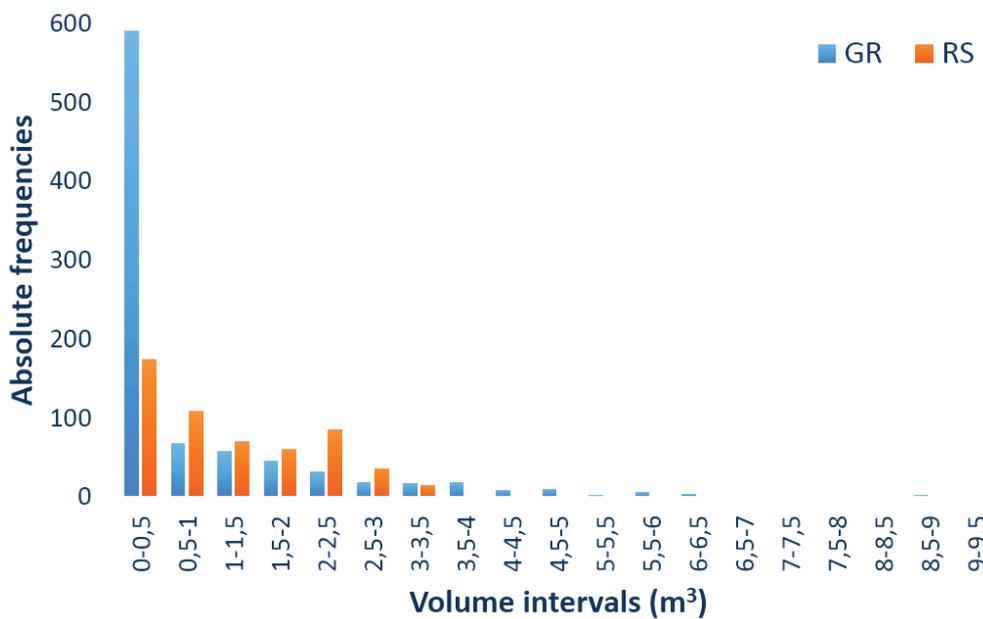


Figure 7: Absolute frequencies of measured (GR) and detected (RS) trees within the volume intervals.

CONCLUSIONS

As expected, the application of the single-tree approach (ITD) using our own algorithm resulted in an underestimation of the count of trees with lower social position. Compared to the mean height of the reference data, it logically resulted in the overestimation of the average remote-based height (8%). The extraction rate of 50% could be improved through a finer calibration of the reFLex algorithm, separately for each tree species, which is one of the perspectives of the software development. Additionally, development of “cut off” regression models is a possible way to estimate the number of understory trees.

The classification of RGB as well as infrared aerial images failed to provide the reasonably accurate tree species composition and thus, as a matter of compromise, just groups of coniferous and

broadleaved species were classified. The solution is probably the development of a new classification scheme for smaller, spectrally more homogenous areas, together with different kind of geo-data and a variety of priory information (i.e., ALS data, reFLex algorithm outputs, forest management plans).

The average diameter of the trees calculated by the regression model based on the reFLex algorithm outputs, differed from the validating data by 8%. However, the accuracy of the selected non-linear functions was just 24%. One possibility for increasing the accuracy is the construction of more complex, multi-argument non-linear models that would imply not only tree heights but also arguments characterising tree crowns and forest stand density. Another chance for improving the accuracy of regression functions lies in the usage of sample sizes which are based on ground reference data only from training and testing plots.

The total difference between RS-based and field-based growing stock was -28%. The resultant growing stock difference was caused primarily by the combination of random and systematic errors of input parameters for volume equations, what calls for the further improvement of their estimation. According to Slovak standards, 15% accuracy on 95% significance level is required for growing stock estimation in close-to-nature (selective) forests.

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