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Research Article

Combining visual interpretation and image segmentation to derive canopy cover index from high resolution satellite imagery in functionally diverse coniferous forests

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Abstract

Forest canopy cover is one of the most significant structural parameters of the forest stand that can be estimated using of aerial and satellite remote sensing. Even though sub-pixel analysis can be used to estimate the index on low-resolution imagery, high-resolution imagery provides more accurate details on forest canopy variability for ecological and forestry applications. However, the high variability of the images demands a more advanced approach to canopy cover measurement than the visual interpretation of single images or stereo pairs. These traditional methods are inefficient and limited in providing a comprehensive and accurate canopy cover assessment. An improvement of the method could involve classifying high spatial resolution images, separating and extracting the areas corresponding to canopy gaps, and generating canopy cover maps. This study offers valuable insights and reveals key differences between three methods for estimating canopy cover: ground measurements, visual photo interpretation and automatic extraction from classified images using pixel and object-based methods. The texture analysis approach was used for separating the "shadow" objects corresponding to gaps in the canopy from the shades cast on the lower trees. The sample plot-based visual interpretation of the images revealed comparable results between ground and satellite image canopy cover values (correlation coefficient of 0.74 for all plots), with lower correlations (r = 0.39) for uneven-aged stands. The results encourage the use of the texture analysis method, with satisfying accuracy (forest canopy cover differences of maximum 0.06 between ground, photo interpreted and extracted datasets). The method could be further integrated with complementary data like LIDAR or hyperspectral images.

Keywords: forest cover; canopy gaps; IKONOS2; image segmentation

Introduction

The forest canopy cover index is computed as a ratio between the canopy projection area and the total area of a stand, as one of the density indices used in describing forest stand structure (Florescu & Nicolescu, 1996). Traditionally, this index was assessed by conducting fieldwork and then incorporated into forest management planning activities. The estimation is performed in most cases by field specialists using visual interpretation of the percentage of canopy cover. The literature also mentions other estimation methods, based on instruments such as densitometers, zenithal photos (ground data) and high-resolution aerial photos (remote

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sensing data) (Bos, 1973; Rusu, 1978). The literature distinguishes between the canopy cover index, defined previously, and the canopy closure index, which is measured using hemispherical photography (Paletto and Tosi, 2009). All these methods are based on visual analysis of the canopy or of the canopy images, requiring a high user input.

In other cases, the canopy density estimation integrates medium and low spatial resolution imagery, such as Landsat ETM (Hadi and Wikantika, 2004; Baynes, 2007; Nasiri *et al*., 2022) and SPOT (Hagner, 2002). In such cases, the main difference consists in using image classification to extract the density indexes. For example, Baynes (2007) describes a software application designed to classify Landsat ETM images and extract the values of certain canopy density indexes. The work routine is based on sub-pixel analysis of 30 m resolution multispectral images and consists of a correlation between the reflectance of the pixel and the percentage occupied by crowns (or shadows) in that particular pixel. Other authors (Hadi and Wikantika, 2004; Nasiri *et al*., 2022) integrate the Landsat images in complex analysis to perform stand volume assessments or to detect forest canopy changes, even at global level (Hansen *et al*., 2013). The accessibility of high-resolution digital imagery (IKONOS, QuickBird, GeoEye and WorldView) makes detailed analysis of forest canopy possible. The one-meter-level spatial resolution images are suitable for both visual photointerpretation and image classification. Classification algorithms are more cost efficient, decreasing the human input in measuring the canopy cover index. In examining the differences between the three computation methods for this index, the problem of the structural type of the stand should be considered, as an influential factor in the accuracy of canopy structure characterization.

In the last years, there has been a significant shift of focus from the general monitoring of forest cover (in the context of deforestation) towards the close analysis of forests that have an associated high value, from both an environmental and social perspective. In such cases, it was argued that the adequate preservation of such forests should be based only on their exclusion from management (set aside), while there are opinions stating that sustainable forest management would actively improve the conservation status of the forest (Grönlund *et al*., 2019; Barbu *et al*., 2023). Either way, such forests need to benefit from structured monitoring done at different levels and scales of analysis, to identify the best information that needs to be included in the decision-making process of forest management.

The research objective of this study is to estimate the canopy cover measurement errors on IKONOS multispectral images, on multiple levels of analysis using visual photointerpretation and image texture analysis, as a starting point in the monitoring of high value forests included in a natural park, with different levels of conservation.

Materials and Methods

Location

The study is located within the Vanatori Neamt Natural Park, in the North East part of Romania (Figure 1). The area is represented by low-altitude mountains (<1000 m) with high productivity mixed forest stands with Norway spruce (*Picea abies* (L.) Karst), silver fir (*Abies alba* Mill.) and beech (*Fagus sylvatica* L.). Part of the area considered for the canopy cover estimations was set aside since 2007 as part of the integral protection area of the natural park (Anonymus, 2016). As a result, the forestry operations were stopped, except for sanitary cuts in areas affected by the bark beetle.

Datasets and materials used

The remote sensing materials used in the research consist of IKONOS images, taken in October 2003 over the entire Vanatori Neamt Natural Park area. The spatial resolution of the images is 1 m in the panchromatic and 4 m in the other spectral channels (blue, green, red and near infrared). The off-nadir angle

of the satellite in the moment of image taking is relatively low, resulting in a spatially accurate image. The moment when the image was taken (October) does not influence our ability to analyse the forest canopy structure, considering the analysed stands are mainly composed of coniferous species (silver fir and Norway spruce). The satellite programming company pre-processes the images, including georeferencing and radiometric correction (Bowen, 2002; Dial *et al*., 2003).

The image processing included the subset and mosaic of the images to obtain a unitary image. To increase the spatial resolution and the contrast for the interpretation, a resolution merge function was performed within the Imagine Professional 2009 software (ERDAS Imagine Tutorials, 2008). The satellite programmer did the ortho-rectification and spectral correction, but data have been verified using Ground Control Points (GCP) (data not shown).

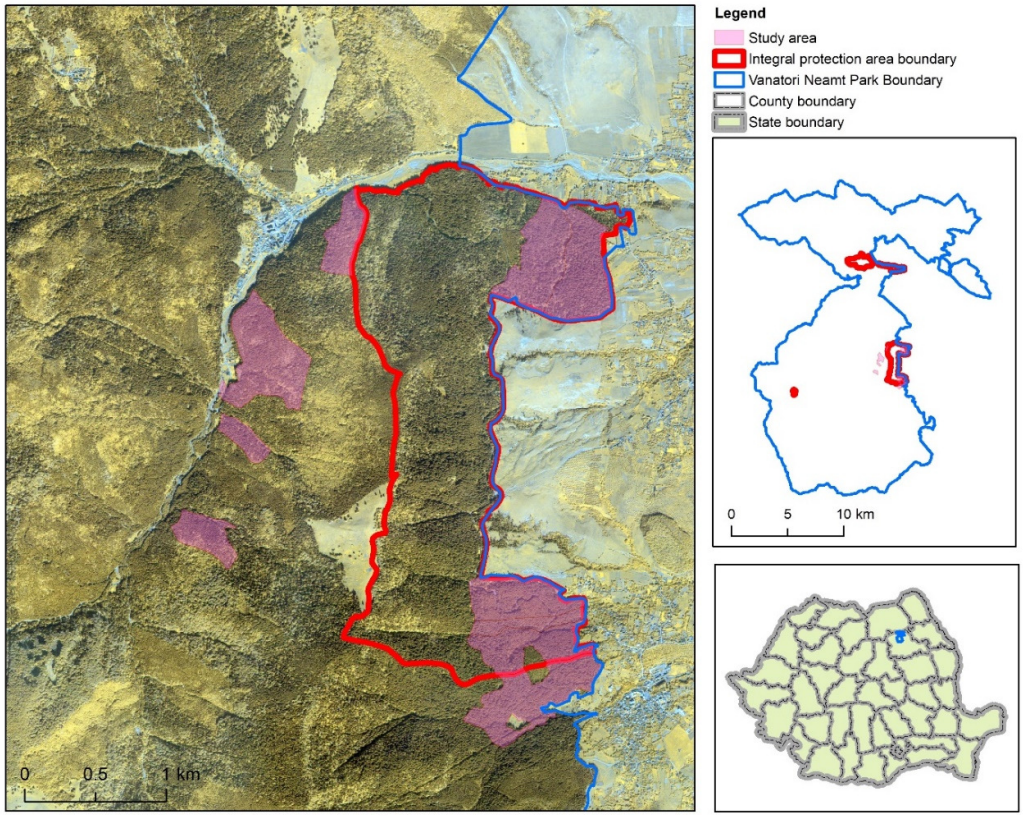


Figure 1. Location of the study (overlay on IKONOS satellite image – used in the study - and state and county boundaries – geospatial.org)

Methods

The methods used to achieve the research objectives could be grouped according to the investigation stage in which they have been involved:

- Field observations of canopy cover index values
- Visual photointerpretation using rectangular networks of points and data comparison
- Per pixel classification using ERDAS Imagine
- Object-oriented classification (eCognition Professional)
- Extraction of the shadows corresponding to the presumed canopy gaps
- Analysis of the results on a forest stand basis

Field observations of canopy cover index (K) values were performed in 173 sample plots installed in 10 mixed stands of Norway spruce and silver fir, homogenous as structure. The canopy cover estimations were integrated into a more complex forest inventory performed in the area (Barnoaiea and Iacobescu, 2009).

The sample plot network was designed at the stand level, using the volume per 1000 m^2 as the parameter for evaluating the representativity of the data collected. We calculated the number of sample plots/stand using Student's *t*-test for stands with less than 30 plots and *u* test for stands with more than 30 plots, with a *p*-value of 0.05 (Horodnic, 2003). Based on the stand's structure, we used an estimated variance coefficient for the volume from Giurgiu and Decei (1997). The post-inventory value of the coefficient (up to 3 %) was lower than initially assumed, and the canopy cover was even lower (up to 30%). Two sample plots were set up 100 meters apart. Each plot was surrounded by a 50 × 50-meter network to visually estimate the percentage of canopy cover within a circular area of 1000 m^2.

The method employed in the field uses visual estimations of the canopy cover percentage from the total area of the stand. The final value of the index resulted as an average between the values given by two operators in the field. A GPS receiver (GARMIN GPSMAP 76CSx) was used to set up the correspondence between the field sample points and the IKONOS image.

Visual photointerpretation on IKONOS images was based on a rectangular network of 100 points located at the intersection of the gridlines; this network was overlaid on the IKONOS image using the GPS coordinates measured in the field (Figure 2).

The IKONOS multispectral images have been subset to obtain an optimum spectral band combination and spatial resolution for the photointerpretation. After several band combinations tested, the best separability for the tree crowns and canopy gaps was found in a mixture of the red, panchromatic and near-infrared IKONOS images. The comparative analysis between the field data and IKONOS photo-interpreted values of the canopy cover index was performed separately for each type of stand structure found in the field, using correlation and regression analysis.

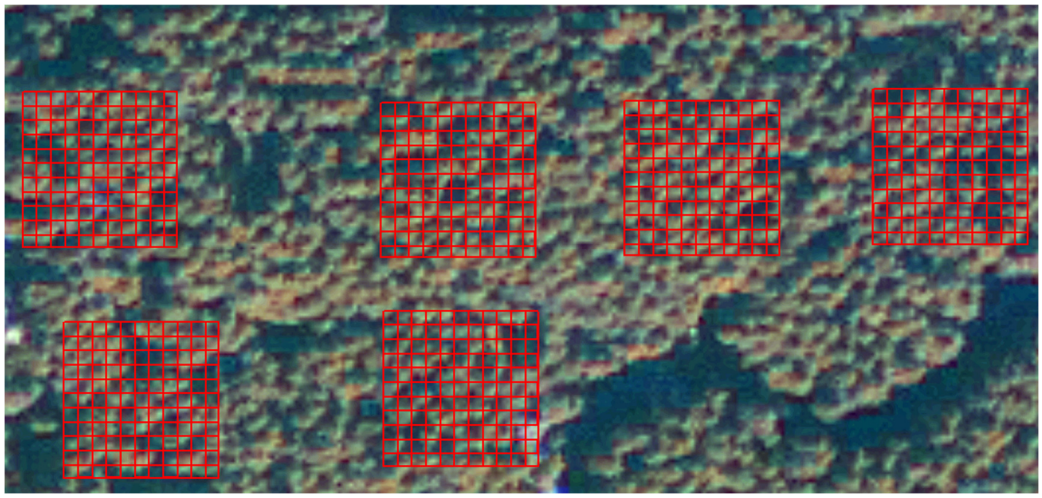


Figure 2. The rectangular networks used for canopy cover index estimation

Image classification

The processed multispectral IKONOS images were subjected to classification using two main approaches: per-pixel and per-object. The per-pixel classification uses statistical methods to frame each pixel of the image in a class according to the spectral characteristics measured in each channel of the available images (de Jong *et al.*, 2004; Lillesand *et al.*, 2008; Wang *et al.*, 2010). Different image classification methods have been tried, to obtain the best accuracy in separating the class "shadow" from the other classes. The best results were obtained through supervised classification using the maximum likelihood and Mahalanobis distance classifiers.

The training areas have been defined using field observation and visual photointerpretation of the images, applied on the red, panchromatic and near-infrared spectral channels (Anonymus, 2014). The pixels corresponding to a particular class can be extracted and counted, applying the boundaries of the stand or other areas of interest using polygonal masks.

The per-object classification was performed with the *eCognition* 4.0 software. This classification is based on textural analysis of the multispectral image and includes the process of multiresolution segmentation and object classification (Tso and Mather, 2009). The image segmentation was performed on a five-layer IKONOS image, using an additional thematic layer as input, initially having the same weight as the image layers (Definiens, 2004). The stand limits were also used in the segmentation process to obtain image objects that would not surpass the stand's boundaries and make the extraction process more difficult. Several input parameters combinations have been tested to obtain the optimum size of the "virtual image "objects. One of the study's hypotheses is that an optimum combination of the segmentation parameters (scale factor, shape factor, compactness smoothness and layer weights) could separate the shadows of the predominant trees cast over the lower trees from the shadows cast on the canopy gaps. After several combinations were tested in the segmentation process, an appropriate combination was found, merging in the best way the characteristics of the stands in the study area (Table 1).

Table 1. The combination of parameters used in the IKONOS image segmentation

Layer	Weights	Scale parameter	Shape factor	Compactness/ smoothness
Blue	1	15	0.6	0.5/0.5
Green	1			
Red	2			
Panchromatic	1			
NIR	3			
Stand boundaries (polygon)	1			

The nearest neighbour method was employed for classification, using as criteria the elements' average value and standard deviation of the pixels contained in each image-object produced by segmenting the original image. These image segments were retrieved from *eCognition* 4.0 along with the spectral parameters and the membership class; the file format is shapefile, and the aforementioned characteristics are attached as numerical attributes.

The classified image was analysed along with the polygon layer containing boundaries of the forest stands inventoried in the field to extract the image objects corresponding to the class "shadows" using two thematic layers: the image objects exported as polygons and the polygons delineated by stands' boundaries (Figure 3).

The comparative analysis consisted of correlation and regression analyses. The data from the field, produced by photo-interpreting and extracting the data from classified images, were further analysed together (for all the sample plots) and separately, stratifying the population according to the stand structure (young and mature even-aged stands, old forest stands, relatively uneven-aged stands). The comparison was also performed at the stand level, with data obtained by averaging the single measurements from the plots. Another metric of the differences between the couples of values from each plot or stand is the root mean square error (RMSE) (Palaghianu, 2009).

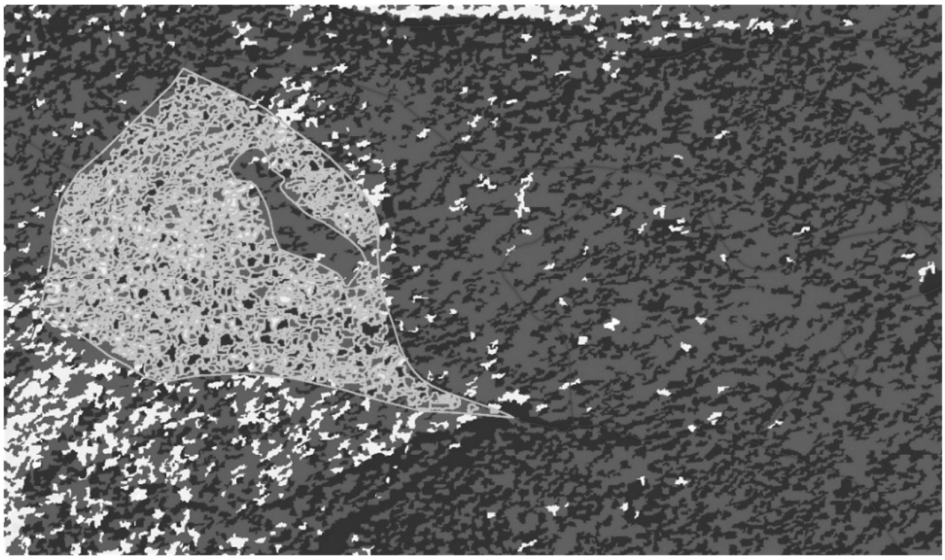
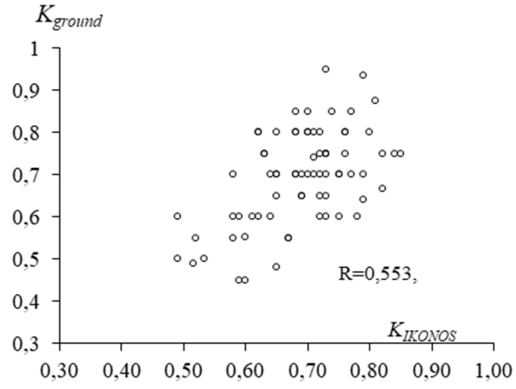


Figure 3. The extraction of the image objects corresponding to each stand by interactive selection

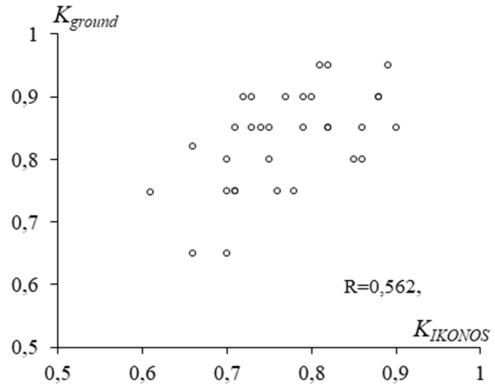
Results

Comparative analysis – visual photointerpretation

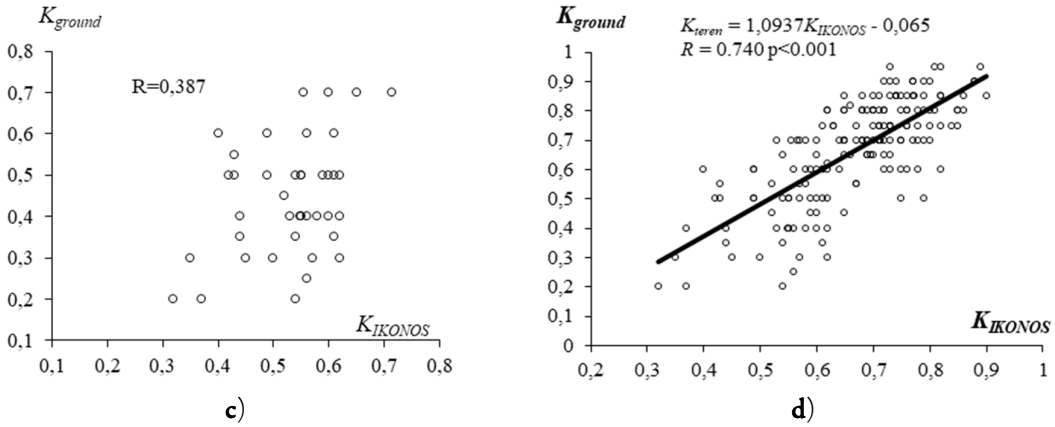
The analysis of the bi-dimensional variations of the values measured in the field and on the IKONOS images respectively shows good comparability, especially for young and mature even-aged stands. The correlation coefficients show strong relations between the variable, even though the variation interval is relatively narrow (0.5 - 1) (Figure 4 a, b). Lower correlations have been obtained in the case of old stands, with low values of the canopy cover index (Figure 4 c).



a)



b)



c) **d**)

Figure 4. Comparison between ground and visually interpreted values of the canopy cover index: **a**) Old forest stands with normal canopy cover; **b**) Young stands with closed canopies; **c**) Relatively uneven-aged stands with vertical closure; **d**) Data from all plots

The integration of all three variation charts (Figure 4 d) highlights the strong relation between the results from the two methods mentioned. The correlation coefficient of 0.740 ($p<0.001$) is very significant for the 173 analysed sample plots. The shape of the point cloud is related to the actual value of the canopy cover index. In the lower left part of the distribution, the variation amplitude is relatively higher than the case of closed stands located in the upper right part of the chart.

The measuring errors of the canopy cover index showed that the distribution of the errors is strongly related to the value of the indicator measured terrestrially. The statistical relation is negative and has a correlation coefficient of 0.740 ($p<0.001$). The errors are positive in stand areas with low closure (overestimates) and negative in the cases of high-density stands (underestimates). The characteristic intervals are 0.2-0.45 (positive errors), 0.5-0.85 (random values), and 0.9-1.0 (negative errors).

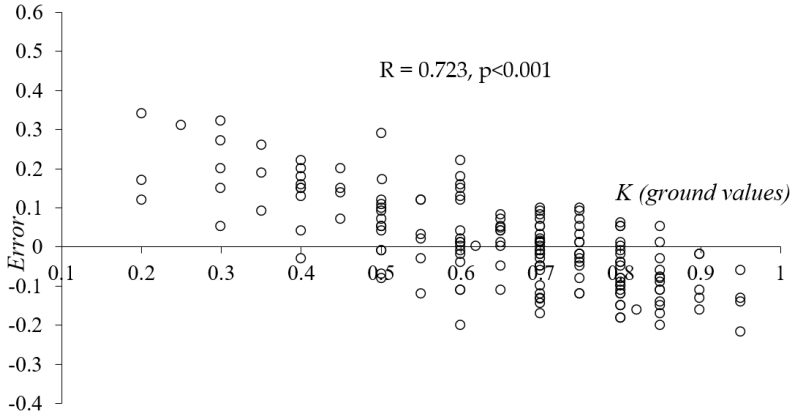


Figure 5. Error variation in relation to the ground values of canopy cover

Image classification and canopy cover index extraction

The image classification process delivered good results in both cases (per-pixel and per-object classification) in separating the shadows from the forest vegetation.

The per-pixel classification provided over 90% accuracy of classification. In several cases, the pixels corresponding to coniferous trees are misclassified as shadows, lacking enough light on the lower parts of the crown. However, the classified images have a large amount of noise due to the high-resolution images with a 1 m spatial resolution. Better results were obtained by applying the texture analysis methods in per-object

classifications. In this case, the segmentation parameters used led to the inclusion of small shadow patches (corresponding to the shadows cast on lower crowns) in the objects containing tree crowns (Figure 6).

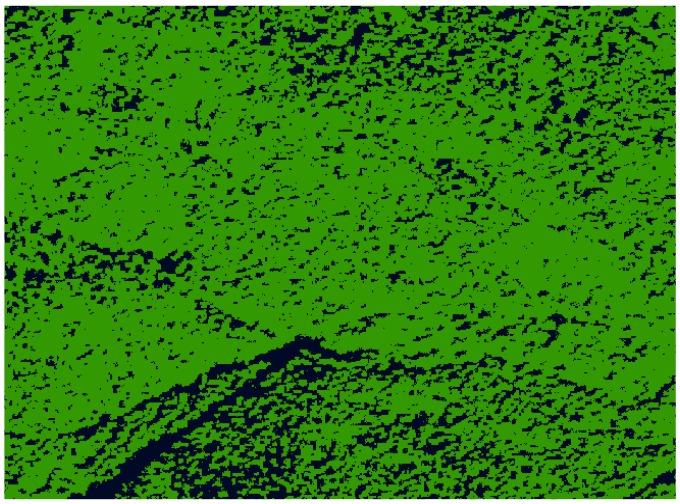


Figure 6. Per pixel classified image

Stand level analysis

The values of the canopy cover index obtained in sample plots installed in the field or by visual photointerpretation have been analysed on a stand level by averaging them without considering the correspondence between the positions of the sample plot (ground and image) (Table 2).

A third set of values was obtained by extracting the values of the index using feature class analysis in ArcGIS 9.3, intersecting the shapefile formed by exporting the image objects with the polygons corresponding to the boundaries of the stands. The values are slightly different in both methods of canopy cover measurement, with lower differences for the images classified by texture analysis. The maximum difference is 0.09 when comparing ground data to photointerpreted values and 0.05 by using feature extraction by class attributes (per object classification). The sets of values obtained by each method have been tested using the Student-test (paired two samples for means) and showed no significant differences between the means (t test value ranging between 0.3-0.4 while the t critical value for our sample was 2.26).

The RMSE of each of the two methods showed different modelling capabilities of the two methods. The RMSE values were 0.06 for plain photointerpretation and 0.04 for the extracted values. The amplitude of errors was also lower in the second case (0.09 against 1.8 in the first case).

Table 2. Stand-level comparison of the canopy cover index values obtained using the three methods

Forest stand	Canopy cover		
	Ground measurements	Photointerpretation	Extraction
32A	0.83	0.77	0.78
30B	0.69	0.60	0.71
34B	0.73	0.69	0.70
36B	0.77	0.77	0.73
26A	0.43	0.52	0.40
25A	0.46	0.54	0.56
17A	0.64	0.65	0.68
19A	0.69	0.67	0.70
20A	0.70	0.72	0.70
22A	0.73	0.69	0.75

Discussion

The canopy cover index is an essential indicator of forest structure, related to the multiple functions of forest ecosystems, with high implications both in the internal pro-cesses (forest regeneration, growth, competition, natural elimination, pruning etc.) and externalities (protection against floods, land erosion and displacements etc.). The standard method of estimation is sometimes ineffective due to the high cost of field data collection and less precise due to an estimation based on several sample plots that might not be relevant for the whole stand.

In Romania, the photointerpretation of aerial photograms has a long history, dating back to the 70' (Bos, 1973; Rusu, 1978) when photointerpretation was used in forest management planning just to differentiate the public forests and pasturelands with trees. The evolution of satellite sensor technology has unveiled the forest canopy in unprecedented detail. Sensors like IKONOS, KompSAT, QuickBird, GeoEye, and Worldview 2 capture images with a resolution of around 1 meter in panchromatic mode, enabling scientists to study individual trees and understand the forest ecosystem like never before. When it comes to the marginal cost of information plugged into the forest management plans, two issues worth being considered: on the one hand, a smaller interest in measuring with high precision the growing stock in numerous protective forests, on the other hand, the tendency to use aerial images in measuring not the growing stock per se but in screening the forest canopy on very large areas, in order to assess how effective the forest governance is, especially the measures undertaken to stop illegal felling (Knorn *et al.*, 2012; Griffiths *et al.*, 2014; Olofsson *et al.*, 2014).

The method based on visual photointerpretation is accurate in measuring the canopy cover index but has low efficiency due to the high number of plots needed at the ground level. The technique is also based on point measurements and needs high statistical confidence. If the sample plot data were stratified on homogenous populations according to the stand's age, structural type and density, the best accuracy would be achieved for relatively even-aged stands with high-density. This should be related to the tendency of close canopy stands to develop only one storey of trees with similar heights. In lesser dense stands, the larger gaps in the canopy allow the light to penetrate to the lower layers where an understorey layer might develop, usually made of some older trees that cover the vertical gaps in between (vertical closure of the canopy).

The higher trees cast shadows on this canopy layer and prevent its visualization, leading to underestimates in canopy cover values. The degree of shading is related to the position of the sun in the moment of image taking and the spectral sensitivity of the sensor (Franklin, 2001). A sensitivity of the sensor in the infrared channels of the electromagnetic spectrum could give information about the areas of the canopy that receive lower illumination. This also explains also the higher weight of the near-infrared image in the multiresolution segmentation. However, systematic errors might also occur in very high density stands, where some trees cannot be spotted even when they occupy the same storey.

The linear regression equation used for modelling the relation between field and re-mote sensing interpretation data is highly representative for the statistical relationship between the two data sets. The *p*-value, characterizing the regression coefficient of K_{IKONOS} is very low (approximately 10-30), showing a very high significance of the factor.

The other methods, based on image classification, consider the entire image corresponding to the stand but must deal with image classification accuracy. An advantage is that the shadow areas have a distinct spectral signature and can be easily separated. In the case of the per-pixel approach, the classification accuracy is acceptable, especially in the case of shadows. However, the method cannot distinguish between canopy gaps and non-illuminated crowns.

The object-oriented approach can be used for separating shadows cast on lower crowns from shadows corresponding to canopy gaps. This possibility is related to the choice of segmentation parameters, which can be found only by multiple tests of value combinations. The conformity of the resulting image primitives can be analysed only by visual interpretation and comparison with the original image (Fu and Mui, 1981; Pal and Pal, 1993; Mustafa *et al.*, 2015). Nevertheless, the choice of parameters could be time-consuming because the values

related to canopy gap separation depend on multiple factors related to stand structure, species composition, sun elevation, and satellite elevation. The method can be optimized by setting up different parameters for different types of forest vegetation structures.

Similar studies show various levels of accuracy in measuring and mapping the canopy cover. The researchers using low-resolution satellite images (Lobell *et al.*, 2001; Saei, M, Abkar, 2004; Baynes, 2007; Shrestha and Suriyaprasit, 2014) measured the accuracy of determination by the overall accuracy of the image classification, often using subpixel analysis to correlate spectral signature to the percent of canopy cover within an image pixel. This accuracy ranges from 70 to 80% in most cases and is related to a relatively large area corresponding to one pixel, area often comprising more than one tree crown. Lobel *et al*. (2001) reach a RMSE of 3% in low variability forests of Oregon, but their comparison is based on aerial photographs of the study area, without any field data assessments. High resolution data use (IKONOS imagery) in the canopy cover variability study in the Brazilian savannahs yielded different results for canopy cover classes: a 0.01 variation on very low canopy cover (0.1-0.2), 0.05 for savannahs with woody vegetation and a RMSE of 0.12 for forest stands found within the savannahs (Asner and Warner, 2003; Asner, 2013). Both low- and high-resolution imagery used in canopy cover assessments yield differential accuracies for different types of stand structures, given by the lack of visibility in the lower parts of diverse canopies.

Even with the precautions that must be considered in assessing the canopy cover by means of satellite imagery, a positive aspect is the high degree of automation of the work. The method can be applied on large areas occupied by forest vegetation, keeping in mind certain precautions in the interpretation of the results. All the image analysis methods should be used with caution in highly dimensionally diverse forests (underestimates of canopy cover values). The studied forest stands include only even-aged and relatively uneven-aged stands, which ensures a good accuracy for canopy cover quantification; the errors tend to increase in size in the case of stands regenerating through various shelterwood systems. The same problems should also appear in uneven-aged forests (natural forests or single tree selection system stands), but the lack of such stands in the study area prevents us from researching this aspect.

Our study highlights that remote sensing techniques, including both visual analysis and automated image processing, can provide accurate assessments of the canopy cover index comparable to traditional ground-based measurements. The image segmentation and texture-based classification offer a robust method of automatic extraction of the tree crowns and separation from the gaps in a more functional model of estimation. Underestimates of the index were observed in diverse forests. The object-oriented approach can offer a "whole image" of the stand canopy, and it can be integrated, with good results, into an automatic shadow extraction methodology.

Conclusions

The forest canopy cover index is one of the essential indices used to characterize forest stand structure, often integrated into the very definition of forest. With the large availability of high-resolution digital imagery, it is now possible to conduct a detailed analysis of forest canopy beyond the results provided by the medium-resolution data used on an extensive scale.

Monitoring individual high-value forests, vital for safeguarding our environment, presents a unique challenge due to the required fine-grained analysis. However, high-resolution imagery combined with powerful texture analysis technology holds the key to unlocking this level of detail.

This study focused on the differences between three methods of canopy cover estimation: ground measurements, visual photo interpretation and automatic extraction from classified images. Our findings indicate the potential of texture analysis as a robust technique that demonstrated impressive accuracy, considering the minimal discrepancies observed in forest canopy cover between ground-based, photo-interpreted, and extracted datasets. However, further investigations are crucial to bridge the gap between these

exciting new techniques and their practical application in large-scale, automated image analysis. Future studies should explore the integration with complementary data sources like LIDAR and hyperspectral imagery, which are becoming more available and hold immense potential for advancing our understanding of forest ecosystems.

Authors' Contributions

Conceptualization, I.B.; methodology, I.B. and CP.; formal analysis, I.B.; writing—original draft preparation, I.B., CP and M.D.; writing—review and editing, I.B., C.P., and M.D.; All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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