AES BIOFLUX

Advances in Environmental Sciences - International Journal of the Bioflux Society

Forest structure analysis on very high resolution images

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Abstract. Forest structure information has been of interest for a long time, being linked to the possibilities of maximizing forest production in terms of ecological stability. Forest structure parameters can be used in assessing the degree of closeness to natural ecosystems for any type of forest stand. The remote sensing methods have the advantage of large scale interpretation of results, facilitating the analysis at different levels – from tree level to landscape level, all this in the context of satellite images price decrease. The high resolution images have their advantages and disadvantages in forest structure assessments but, accurate information about the forest ecosystems can be obtained with the right processing techniques. The evolution of satellite sensors parameters has lowered the analysis level from the landscape level somewhere close to tree level; the modern very high spatial resolution satellites have a spatial resolution similar to medium scale aerial photos, with the advantage of price and multispectral characteristics. The different spectral channels can be sensitive to several forest parameters and, in the right combination, can offer an "image" of forest state and structure. Before using the data extracted from satellite images, is important to make accuracy studies and establish the correct level of analysis. In this context, the paper's objective is to analyze the possibilities of measuring forest structure parameters on IKONOS and aerial images and establish the optimum level for information processing. The parameters taken into account were crown diameter, canopy cover index and number of trees per area unit; the forest stands are consisting of mixed forests of silver fir and Norway spruce, with a high homogeneity. The results of the study showed that a better accuracy is obtained on IKONOS rather than aerial photos, especially in the case of crown diameter and canopy cover index; in the case of number of trees per area unit, the two types of images being similar. In both cases, remote sensing methods tend to reduce the variability of the data, in comparison to ground methods. The best comparability of data is achieved at the stand level, even if the information is originating from measurements of individual trees (as in the case of crown diameter). The conclusion that should be drawn from this study is that the level of analysis can be lowered even to the tree level, but the data should be analyzed on a stand level for better comparability.

Key Words: IKONOS, crown diameter, canopy cover, tree thickness.

Rezumat. Informaţiile privind structura pădurii au prezentat interes o perioadă lungă de timp, fiind legate de posibilităţile maximizării producţiei pădurii în condiţiile asigurării stabilităţii ecologice. Parametrii de structură ai pădurii pot fi folosiţi la evaluarea gradului de apropiere de ecosistemele naturale a oricărui tip de arboret. Metodele specific teledetecţiei au avantajul interpretării rezultatelor la scară largă, facilitând analiza la diferite nivele – de la arbore la peisaj, toate acestea în contextul scăderii preţului imaginilor satelitare. Imaginile satelitare cu rezoluţie spaţială ridicată au avantaje şi dezavantaje în evaluarea structurii pădurii dar se pot obţine informaţii precise despre ecosistemele forestiere folosind tehnicile de prelucrare adecvate. Evoluţia parametrilor senzorilor satelitari a adâncit nivelul de analiză de la peisaj undeva aproape de nivelul arborelui; sateliţii multispectrali moderni au o rezoluţie spaţială au o rezoluţie spaţială similară cu fotogramele la scară medie, având avantajul preţului şi a caracteristicilor multispectrale. Diferitele canale spectrale pot fi sensibile la anumiţi parametri ai arboretului şi, în combinaţia potrivită, pot oferi "o imagine" a stării şi structurii pădurii. Înainte de a folosi datele extrase din imaginile satelitare, este importantă elaborarea unor studii privind precizia şi stabilirea unui nivel corect de analiză. În acest context, obiectivul lucrării este acela de a analiza posibilităţile de măsurare a parametrilor structurii pădurii pe imagini IKONOS şi fotograme şi să stabilim nivelul optim pentru procesarea informaţiilor. Parametrii luaţi în considerare au fost diametrul coroanei, indicele gradului de acoperire a coronamentului şi numărul de arbori pe unitatea de suprafaţă; arboretele sunt formate din păduri de amestec cu brad şi molid, cu un grad mare de omogenitate. Rezultatele studiului au dovedit că o precizie mai ridicată este obţinută pe imagini IKONOS decât pe fotograme, în special în cazul diametrului coroanei şi a gradului de acoperire a coronamentului; în cazul numărului de arbori pe unitate de suprafaţă cele două tipuri de imagini având rezultate similare. În ambele cazuri, metodele de teledetecţie tind să reducă variabilitatea datelor, în comparaţie cu cele utilizate în teren. Cea mai bună comparabilitate a datelor este obţinută la nivel de arboret, chiar dacă informaţia provine din măsurători individuale ale arborilor (cum este cazul diametrului coroanei). Concluzia care ar trebui trasă din acest

studiu este aceea că nivelul de analiză poate fi coborât chiar până la arbore, dar datele ar trebui să fie analizate la nivel de arboret pentru o mai bună comparabilitate şi precizie de determinare.
Cuvinte cheie: IKONOS, diametrul coroanei, grad de acoperire a coronamentului, desime.

Introduction. The requirements of nowadays forestry and nature preservation involve a thorough knowledge of the forest structure, with regards to both quantifiable and qualitative parameters. The efforts to model forest structure are important in establishing whether a forest is "organized" in a close to nature manner or not. These efforts have been materialized in the study of biometrical parameters by comparing the data resulted from the inventory of cultivated forests against the models established in natural forests with the same composition and habitat.

The results are useful in predicting the productivity and stability of a forest ecosystem based on how similar its structure is to optimum structure, corresponding to the habitat conditions. The methods used for high precision determinations on forest structure are also expensive and time consuming. In this context, the means of remote sensing can be used to extend forest structure observations to a landscape level with relatively low costs, accepting a reduced precision towards the terrestrial methods.

The level of analysis of the forest by remote sensing means depends on the available images and the structures of the stands that are taken into account; Franklin (2001) presents three levels of analysis. The first level is represented by the information regarding the vegetation cover and its general characteristics; this information can be easily extracted from LANDSAT imagery, even if the spatial resolution is not very high. The level II information refers to identifying and mapping forest types and forest formations; the analysis process can include in this case the association of the satellite images with topographic information (DEM) and other GIS data available (Lillesand & Kiefer 2000), the image processing with per pixel and per parcel classification (Kayitakire et al 2002). In case of level III analysis, the information is related to individual trees and its characteristics: specie, crown diameter, crown transparency, even individual height and stem volume per area unit (Astola et al 2004; Popescu et al 2002, 2003, 2004).

In this context, the objectives of the paper are to analyze the possibility of extracting the values of several structural parameters by using satellite and aerial images, images with a sufficient spatial and radiometric resolution, required in forest characterization. The parameters taken into account are the average diameter of the crown, the canopy cover index and the number of trees per area unit.

Study area. The study is located in the North East of Romania, in The Vanatori Neamt Natural Park. The mixed forests located in the lower mountain region in Romania represent a great study material regarding the aspects of forest structure.

The main tree species found in these forest ecosystems are silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* L.) and beech (*Fagus sylvatica* L.). Alongside these species we have sessile oak (*Quercus petraea* Liebl.), silver maple (*Acer pseudoplatanos* L.), scots pine (*Pinus sylvestris* L.), Austrian pine (*Pinus nigra* L.). Even though the species composition is diverse, the main forest type is represented by the mixed forests of coniferous and beech, with a high proportion of silver fir in the composition; given their importance, these forest represent the object of the study.

Taking into account the fact that the precision of the measurements is a function of forest characteristics, the terrestrial forest inventory has been conducted in diverse conditions regarding stand age, canopy cover, and species composition.

Material and Method. The remote sensing methodology is based in most of the cases on models resulted by comparing ground data and the data extracted from the satellite or aerial images, following the next pattern (Lillesand & Kiefer 2000): the installation of georeferenced sample plots for inventory, the extraction of forest parameters values from the remote sensing images, the comparison between the ground and remote sensing data, the validation of the determination model by testing it in similar conditions.

In order to find the optimum approach for measuring forest parameters on satellite and aerial images there has been used a multilevel analysis on forest inventory:

- *Tree level approach*, applied in a sample plot of 1 hectare, with 364 trees;
- *Sample plot level* – applied in 72 sample plots with an area of 1000 m^2;
- *Stand level* – applied in 4 different stands with homogeneous characteristics;

The differential approach of the biometrical parameter measurement is important in establishing the analysis level that is applicable on IKONOS 2 images and aerial photos (Franklin 2001), taking into account the estimative character of remote sensing measurements, compensated by the possibility of large scale analysis.

The geomorphologic conditions are similar in all cases: low declivity slopes with Eastern exposure, at an altitude of approximately 700m, similarity important for the equivalence of the extracted data.

The imagery used for forest parameters extraction is represented by IKONOS 2 satellite images of the Vanatori Neamt Natural Park and aerial photos, orthorectified and georeferenced within the LPIS Program (**L**and **P**arcel **I**dentification **S**ystem), both of them with a spatial resolution of approximately 1m in panchromatic. Regarding the spectral resolution, the IKONOS image used had four spectral channels aside from the panchromatic: blue, green, red and near infrared, with a 4m spatial resolution. The spectral bands have been merged with the panchromatic, using the *resolution merge* function of the ERDAS IMAGINE software, resulting in 1m resolution combined image.

Field data. The field inventory has been conducted separately in the sample plot of 1000m^2 and 1ha. In the 1ha sample plot, the biometric parameters taken into account were: diameter at breast height (in cm, measured on two perpendicular directions), total height (m), pruned height (m), relative position of the trees (Kraft classes). The 3D position of the trees has been measured with the total station, using start points with absolute coordinates (Fig. 1).

The sample plots of 1000m^2 have been installed in four mixed forest stands of silver fir and Norway spruce, using a rectangular network, with a density of approximately 1plot/0.6ha, computed according to representativity criteria (Giurgiu 1972).

The inventory parameters were DBH (cm), average crown diameter (m), height (m) and canopy cover index. The position of the center of the plot has been measured with a GPS receiver (Garmin 76CSx) using the stand-alone method. For better precision, the GPS was set to record several positions of the point (*tracking mode* on) and the final coordinates resulted as an average of those coordinates. Is difficult to use more precise methods because of the thick foliage cover (high precision GPS receivers need a minimum of 15^0 off nadir gap in the canopy).

One of the reasons for choosing 1000m^2 plots was the need to characterize a certain portion of the stand using the data inventoried in the sample plot (we considered the 1000m^2 plots to be representative for the surrounding area, compensating for the positioning errors).

Remote sensing data. The area of the study is covered by IKONOS 2 satellite images, panchromatic and multispectral, and orthorectified and georeferenced aerial photos, taken in the visible range of the electromagnetic spectrum. The measurements on the crown have been done using *Erdas Imagine* Software and ArcGIS 9.2, after identifying the position of the sample plots on the satellite and aerial images (Fig. 1).

The *crown diameter* was measured on two perpendicular axes of the crown using the coordinates of the points on the limit of the crown. The program insures high precision of measurements, but the real precision is limited by the spatial resolution of the image (1m).

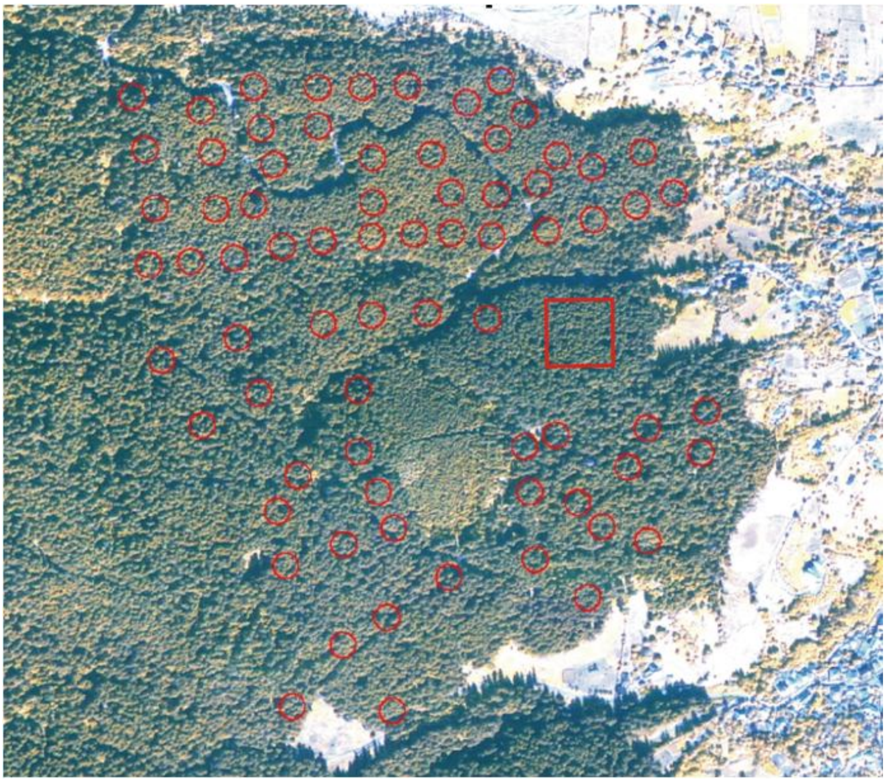


Fig. 1. Distribution of sample plots in Agapia Production Unit

The density of the stand (*canopy cover index*) is measured on the image by applying a rectangular network of 100 points over the position of the sample plot, and expressed as a percent of the points corresponding to tree crowns (Fig. 2). The number of trees has been determined by counting the trees inside one plot (trees with more than one half of the crown inside the plot).

In the 1 ha sample plot, the tree crowns have been outlined in ArcGIS and presented as polygons (Fig. 3a). The result of the delineation was compared with the horizontal profile of the plot resulted from ground measurements (Fig. 3b). From the digitized image of the sample plot we could extract the crown diameters and density indexes of the stand and compare them with the ground data.

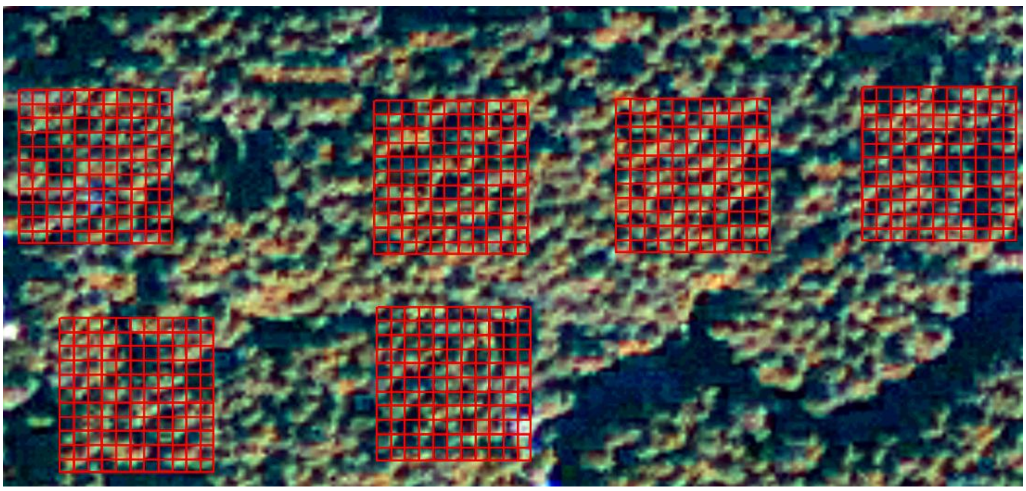
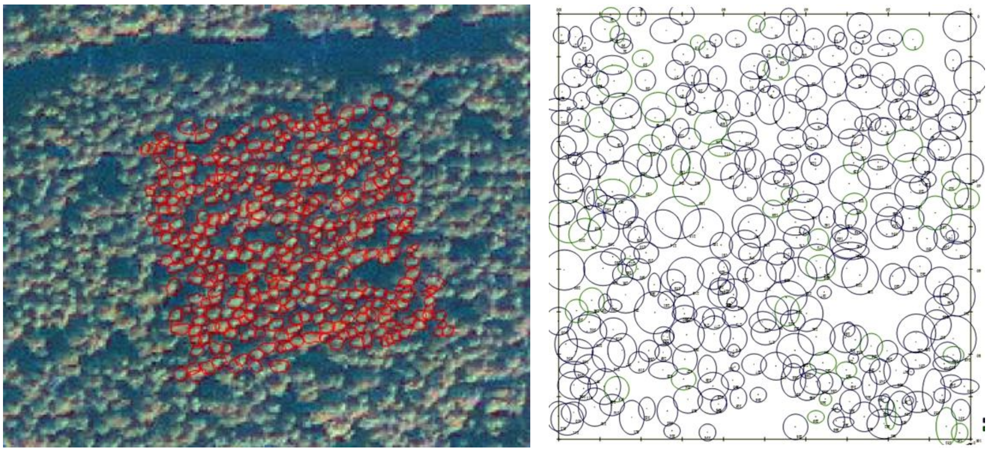


Fig. 2. The networks used for canopy cover index computing



a. b.

Fig. 3. a. Tree crown delineation on IKONOS image (RGB combination – NIR-Panchromatic-Red) in the 1ha sample plot; b. horizontal profile of the 1ha sample plot resulted from terrestrial measurements

The crown diameters and density indices were measured on the image and compared with the values obtained trough terrestrial inventory; all comparisons are based on a statistical analysis of significance and correlation.

Results and Discussion. The multilevel analysis of structural parameters of the forest is important in establishing the approach on forest structure by means of remote sensing (Franklin 2001). The analysis will be done from a particular to a general view, starting with a tree level analysis (in the 1ha sample plot) and finishing at the stand level, comparing the average values and variability indices characteristic for each stand taken into consideration within the study.

Tree level analysis

Given the fact that in the case of 1 ha plot there is a strict correspondence between the ground data and the measurements on the satellite image, the data will be compared at a tree level using, besides crown diameter, the relative position of the tree (Kraft class) and the pixel values in each. The correlation between tree crown diameter measured from the ground and the values extracted from the digital images is 0.533*** for silver fir and 0.606*** for Norway spruce, both being very significant.

The dispersion of the values is high but the point cloud is located approximately on the diagonal of the diagram (Fig. 4), with a tendency of underestimating large crown diameters. The correlation coefficient is good, but leads to a determination coefficient of approximately 0.3, which is not satisfactory. The analysis of crown diameters distribution (Fig. 5) shows a decrease in variability in case of remote sensing values. The interval in which we can find the remote sensing values is 4.6m, unlike the terrestrial values, spread within a 9.0m interval. An interesting fact is that the measurement error (computed as a difference between remote sensing values and terrestrial values) is very highly correlated with the value of the crown diameter (terrestrial measured values). The correlation coefficient is -0.821, very significant for the 364 considered values.

The "-" sign of the coefficient shows that largest error values are encountered in the case of small crown diameter trees. This is understandable if we take into account the fact that these trees occupy a lower position in the canopy and most of their crown is covered by the crowns of dominant trees in their proximity; even if the tree tops can be identified, the overlaps of the tree crowns are a source for consistent errors in crown diameter measurements (Fig. 3).

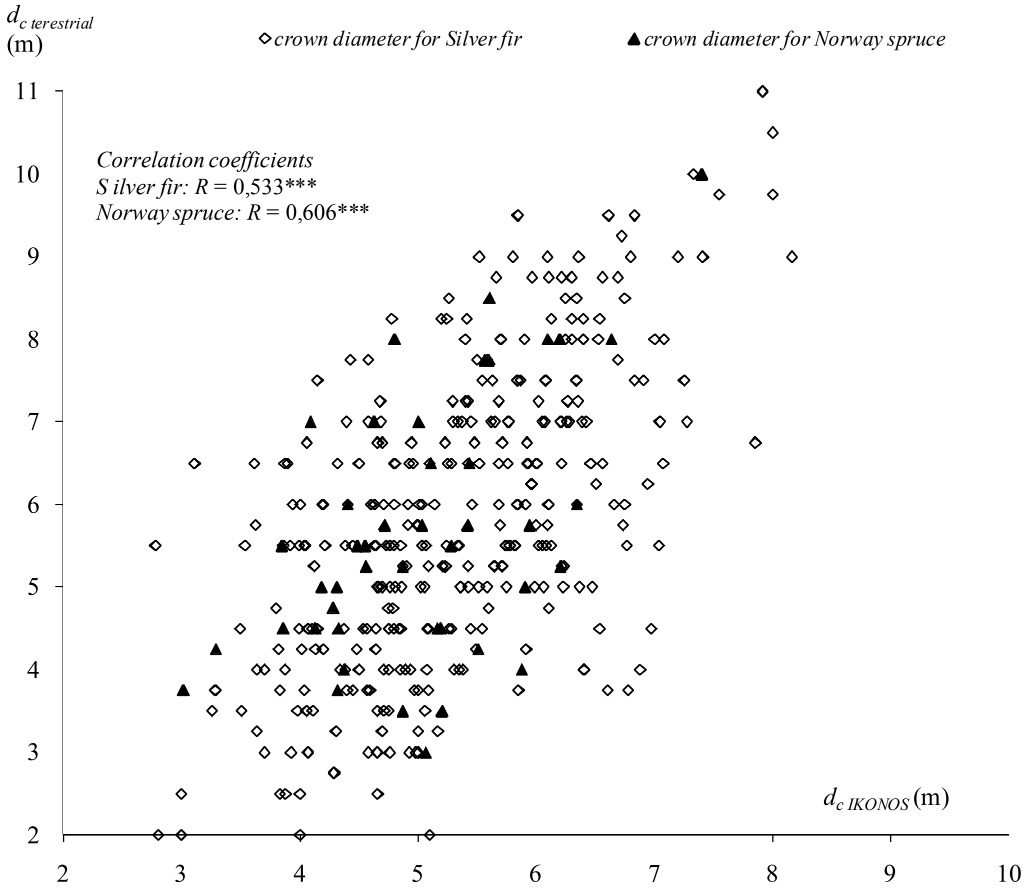


Fig. 4. Correlation between the values of crown diameter measured from the ground and on the IKONOS 2 satellite images

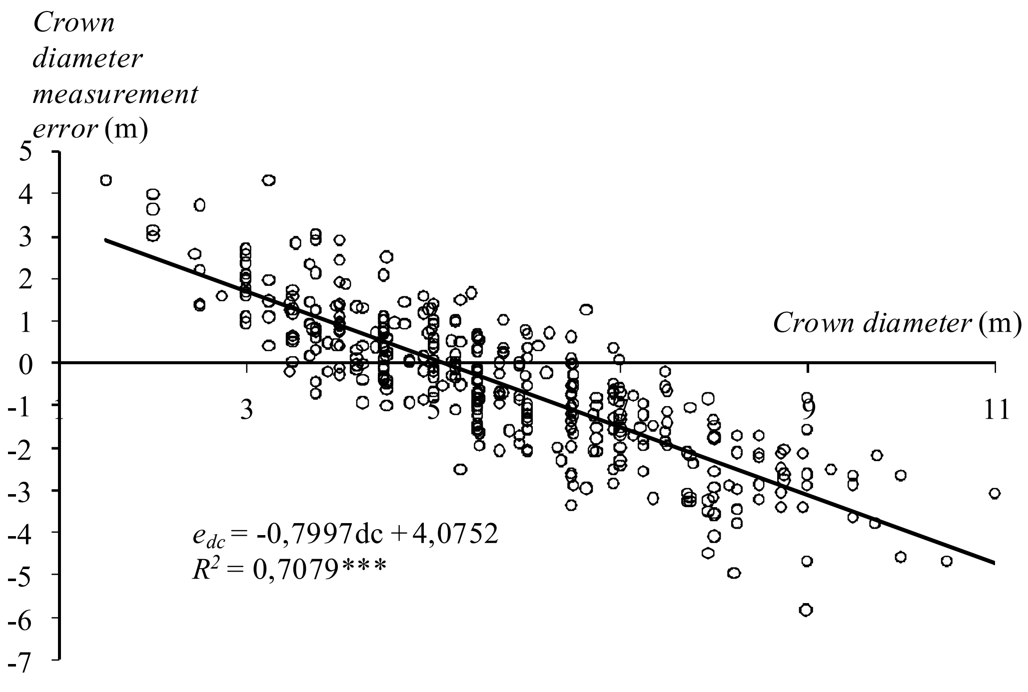


Fig. 5. The correlation between the measurement error and the crown diameter for the 1ha plot

However, these errors do not affect the average crown diameter very much; the terrestrial value of average crown diameter is 5.7m, different than the remote sensing value, respectively 5.2m. The difference is statistically significant when tested with the *Student* test, assuming unequal variances. One can also notice that the measurement errors for trees with crown diameters close to the average value are around zero (Fig. 5); also, the errors are positive for small crown diameters and negative for large diameters.

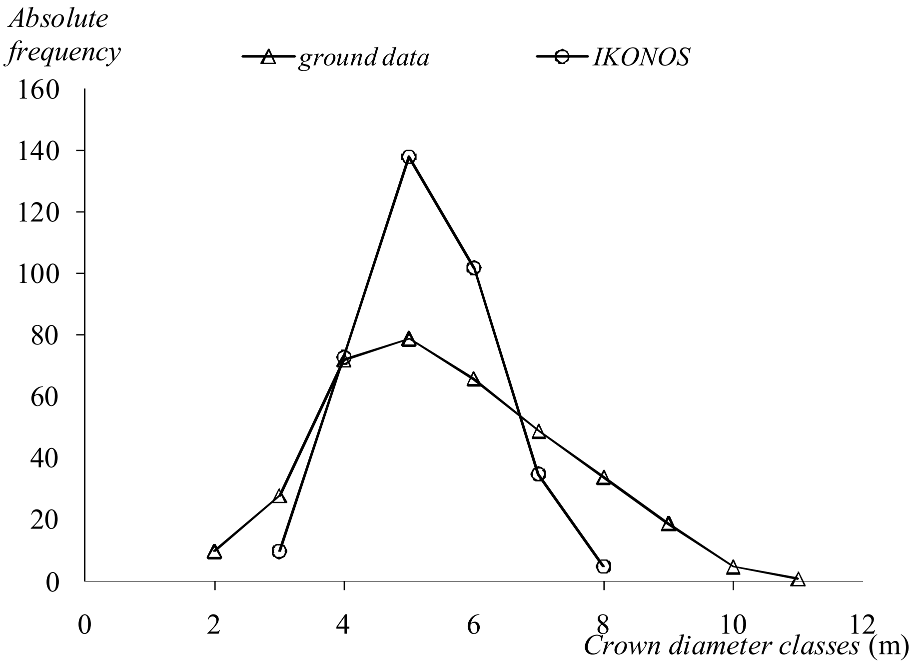


Fig. 6. The experimental distribution of trees on crown diameter classes in the 1ha sample plot based on terrestrial and remote sensing measurements

The decreased variability of remote sensing data reduces the applicability of crown measurement in direct computing the indicators of structural diversity; however, the data can be used in comparison with the spectral signature of the trees, a source of valuable information in assessing the spatial variability of forest parameters.

Sample plot level analysis

For the plot sample level, the comparison has been made between the average data from the ground and from the satellite images. The average values are accompanied by the variance indicators (standard deviation, variation coefficient) necessary in determining the effect of remote sensing measuring on parameter variability.

The **crown diameters** have been measured on IKONOS satellite images and plotted against the ground data (Fig. 7). The result of the statistical analysis is a R^2 = 0.642 determination coefficient, very significant for the 72 plots taken into account. One can notice that in this case the point cloud is located around the diagonal of the diagram, with a slope of the trend line close to 1 (0.9672), meaning that there are no significant systematic errors affecting the determination of average crown diameter for each 1000m^2 sample plot.

The problem with applying remote sensing methods in mixed resinous forests is that IKONOS imagery can't show the specie of each tree that is being measured. In previous research (Barnoaiea & Iacobescu 2004), significant differences could be noted between the species spectral signature, but only in pure and almost pure composition stands. In the research area of this paper, the stands are composed in a very high proportion by silver fir (*Abies alba*) – 80-90% and the Norway spruce is disseminated within the stand; besides that, the spruce crowns are located in the lower part of the canopy due to the smaller heights of the trees. The effect of this position is that most Norway spruce crowns do not receive enough light in order to reflect properly and subscribe to the spectral signatures measured in pure stands. Even though the literature (Bos 1973) mentions photo-interpreting keys for tree species based on the form of the crown, it can only be applied on very high resolution images (especially aerial photos), and not on IKONOS images. However, the similarities between the two species extend beyond the spectral signature; they also have similar growth rates and similar stem form parameters, similarities that reduce the errors caused by the fact that the specie is not taken into consideration for example in stand volume assessments.

The trees belonging to other species than the dominant ones could be better identified on aerial photos (for dominant trees), but the correlation between the ground and aerial photo measured crown diameter is less intense than in the case of IKONOS images (the correlation coefficient between ground data and the crown diameters measured on aerial photos is less than 0.2). The reason can be found in the high declination degree of photo taking from the plane, resulting in side views of the crowns and modification of crown parameters.

The density of the stand has many forms of expression (Giurgiu 1979), but the most used is the canopy cover index, computed as the ration between the canopy projection on the soil and the entire area of the stand, with values ranging from 0 to 1. It is the simplest way to asses stand density and is strongly related to the intensity of soil protection functions of the forests (Cenusa 1996).

The remote sensing methods for **canopy cover index** computing have long been mentioned in the literature (Bos 1973; Rusu 1978); what is intended in this study is to make a precision estimation of remote sensing methods for the canopy cover index, compared to terrestrial measurements. The measurements have been made by applying a rectangular network on the image of each sample plot (Fig. 2) and by counting all points that correspond to the canopy.

The results are once again in the favor of IKONOS images measurements. The determination coefficient in this case is 0.372, corresponding to a correlation coefficient of 0.610***, unlike in the case of aerial photos, where the values of these coefficients were 0.240 and 0.489***. One can notice that the coefficients are very significant for the 72 plots taken into consideration, but also the difference between the two measurements methods.

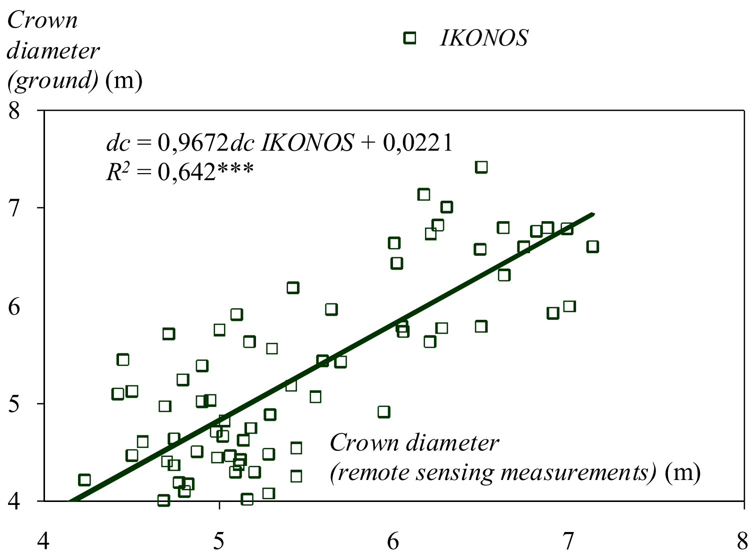


Fig. 7. Correlations between two methods of tree crown diameter measurement – terrestrial and remote sensing

An advantage of satellite image measurement in this case is the fact that the trendline in this case has a slope closer to 1, corresponding to a more accurate measurement (0.69 for IKONOS and 0.412 for aerial photos). The cause for these differences can be explained, as in the case of crown diameter, by the smaller off-nadir angle of the photographing axis, as in the case of satellite images. Another advantage in this case is given by the fact that all the projection axis are quasi parallel due to the relatively high distance between the sensor and the active reflection surface; this is translated (in images of forests) in a constant overlapping of crowns throughout the image – not variable as in case of aerial photos (Lillesand & Kiefer 2000) (Fig. 8).

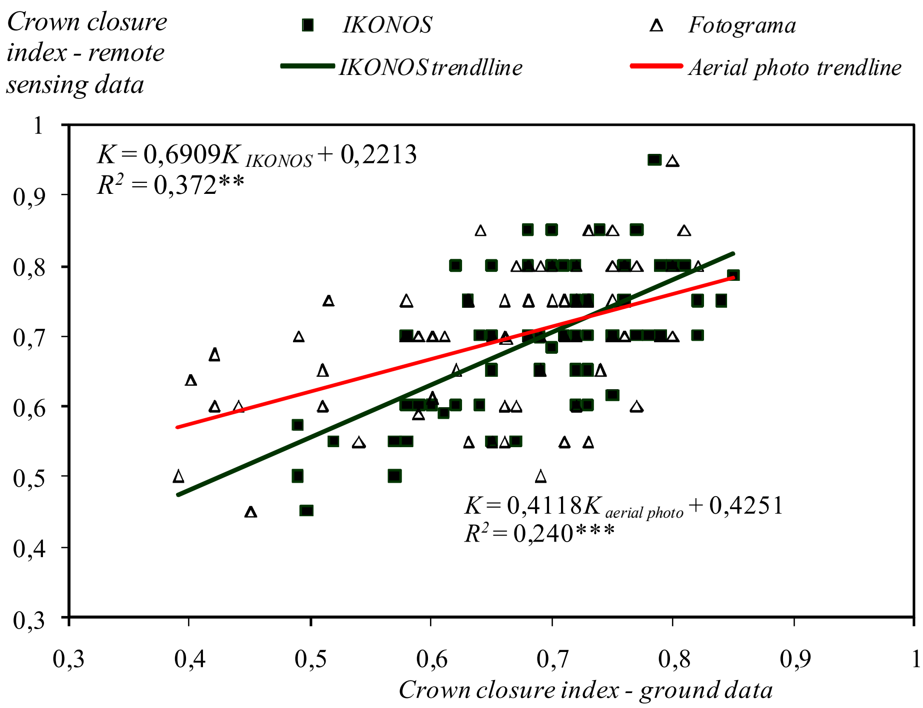


Fig. 8. Comparison between terrestrial and remote sensing measurements of canopy cover index

Another stand density indicator is the number of trees found on an area unit (generally expressed by reporting to 1 hectare). The dynamics of this parameter throughout the development of a forest stand is characteristic for each type of forest ecosystem. The yield tables provide, for each species, productivity class and age a number of trees per hectare considered normal for a cultivated pure even aged stand (Giurgiu & Decei 1972). These numbers are a precious auxiliary in designing most of the interventions during stand development, between the stages of sapling to old forest. In this context, being able to estimate the number of trees per area unit is an important factor for decision support in forest management.

The comparison between ground data (considered most accurate) and remote sensing data showed a comparable correlation in both cases – IKONOS images and aerial photos, with a significant advantage in correlation for IKONOS data. The determination coefficient for IKONOS is 0.446, corresponding to a correlation coefficient r = 0.668***, while these values for aerial photos are 0.346, respectively 0.588***. One can notice that, in both cases, the coefficients are very significant, but the remote sensing methods explain less than 50% of the parameter value (determination coefficient R^2<0.5).

A question could be raised here about the fact that the number of trees per plot is sometimes larger than the one from terrestrial measurements. The fact could be explained by two causes: first, the combination of the bands used as a basis for the measurement lead possibly to fragmentation of the crowns due to the some variations in crown reflection and second, the inventory is still a statistical one; even if the center of the plot is perfectly over posed on its corresponding place in the images, we still wouldn't take into account the exactly same trees as we did from the ground, due to stem deviation from the vertical and to crown asymmetry. In this context, it is important to admit that the precision analysis should be performed on different levels first, in order to draw the proper conclusions.

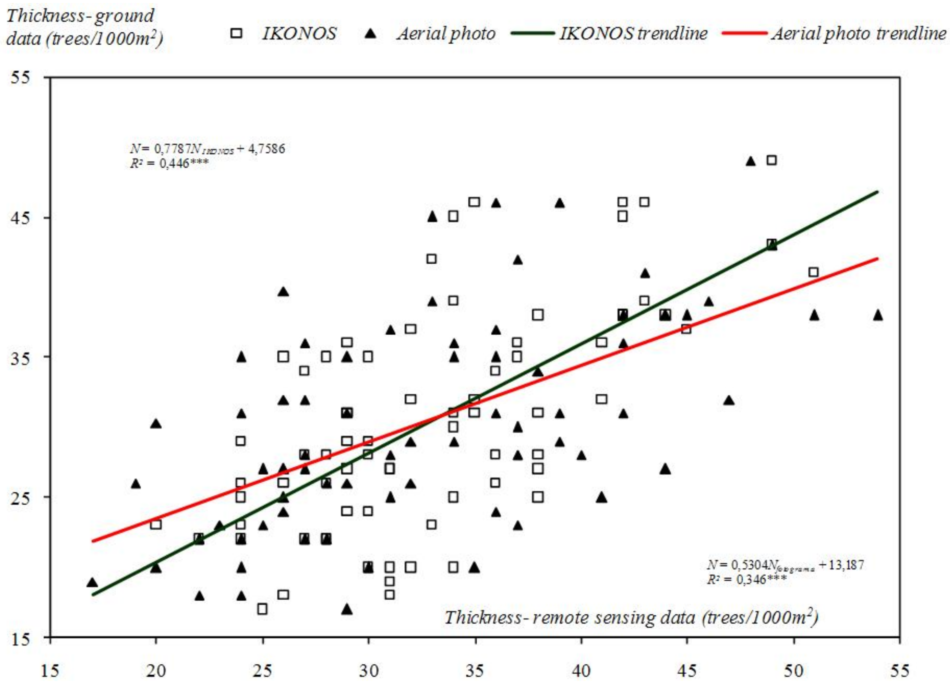


Fig. 9. Comparison between the number of trees per plot measured terrestrially, on aerial photos and on IKONOS images

Stand level analysis

For this level of analysis four different stands have been taken into account. The ground data available is the same as in the previous analysis (plot level), but in this case is being processed in groups, corresponding to stands. This level of analysis does not need to take into consideration the geo-referencing of the sample plots due to the correspondence between the limits of the sands, easy to observe also from above and beneath the canopy. An important aspect of this level of analysis is that the data in sample plots have to be representative for the entire stand (with a certain confidence level). This condition has been accomplished in the present study within the inventory designing stage, taking into consideration the variation coefficient of the characteristics, the established maximum error and the confidence interval.

The analysis shows significant correlation between the ground and remote sensing data: the differences between the average crown diameters of the stands measured by the two methods are less than 0.3m, meaning a maximum of 4% of the average crown diameter. The error is insignificant and, as one can notice, there are no systematic errors – the method does not systematically reduce or increase the values, compared to what was measured from the ground.

Is important to notice that, because the scientific literature in the matter mentions a systematic error – obtaining lower crown diameters because of lower branches that do not appear on the image (Rusu 1978). When taking the average value into account, the underestimates that appear on dominant trees are compensated by the overestimates done in the lower part of the canopy (dominated trees might not be taken into account). This explains also the decrease in variability of remote sensing values (§ 4.1) – the most important errors appear at the sides of the distribution.

The analysis of variation coefficient at stand level shows that there is a systematic underestimate of this parameter. In fact, the data tend to be correlated significantly and with a high coefficient. The problem is that the number of stands is relatively small and any statistically analysis is inadequate. On the other hand, these results can be a basis for further analysis – there should be more stands included in research and the data used for the validation of the analysis model presented. An important aspect is that the overall accuracy of average crown diameter assessment is good (the average diameter for all stands is 5.27 m in IKONOS measurements and 5.36 m in the case of ground measurements).

Table 1

Stand-level comparison between ground and remote sensing measured average crown diameter

Stand	*Average crown diameter – ground data (m)*	*Average crown diameter – IKONOS data (m)*
17A	6.4	6.5
19A	4.9	5.1
20A	5.2	5.2
22A	4.7	4.9

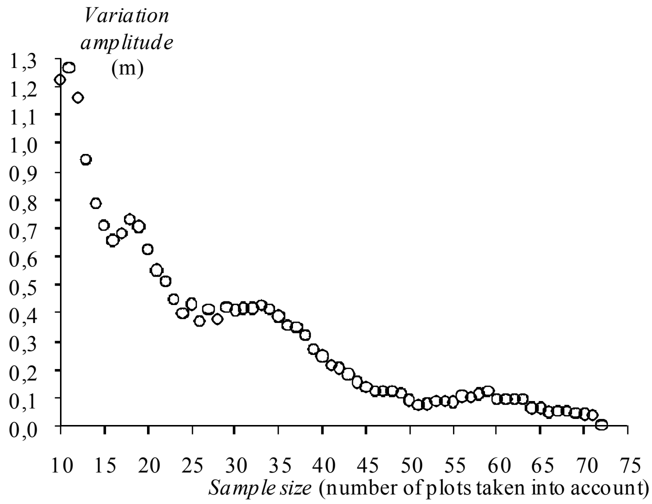


Fig. 10. Reduction of difference between IKONOS and ground values of average crown diameter

Analyzing the decrease of the average crown diameter error with the number of plots taken into consideration (Fig. 10), one can notice that an acceptable precision could have been achieved with lower inventory intensity. A precision of 0.2 m for example could have been achieved by taking into consideration only 40 of the plots. The sampling that led to the variation chart below has been made systematically and looked over all possible combinations between the statistical units.

The comparison of density parameters in the case of terrestrial determinations and remote sensing data showed no significant differences regarding the average value of the parameters (Table 2).

Table 2

Comparison between density indices resulted from ground measurements, aerial photo and satellite images measurements

Stand ID	Average number of trees per plot (trees/1000m^2)			Canopy cover index		
	Ground data	IKONOS	Aerial photo	Ground data	IKONOS	Aerial photo
17A	26.5	26.6	25.7	0.64	0.65	0.57
19A	25.0	26.5	23.6	0.69	0.67	0.73
20A	33.8	32.3	32.2	0.7	0.72	0.71
22A	34.8	32.9	31.3	0.73	0.69	0.71
General average	30.6	28.5	29.9	0.69	0.69	0.66

The average values of these parameters are very close to ground measurements, suggesting a stand level optimum interpretation of data. However, the variability of the data from each plot is smaller in each case is smaller in case of remote sensing data than the ground measured values. This reduction is to be considered when analyzing spatial variation of density indices within the stand; it could be of help to extend this analysis in more cases and construct a regression based model for data variability interpretation.

Conclusions. The use of remote sensing is related to the objectives of the photointerpretation process, the available imagery and the characteristics of the active reflection surface. It is a precious auxiliary in forest structure description, especially when the objectives involve large area analysis.

The crown diameter analysis done on a tree level shows an approximately 0.6 correlation coefficient, statistically significant for the 364 trees taken into consideration. The difference between the average values obtained by the two methods is statistically significant and shows an underestimate in the case of IKONOS image measurements.

The variability of IKONOS measured values of individual tree crowns is lower than the variability of the same data measured terrestrially; the decrease is explained by an inverse correlation between the value of the error and the value of individual tree data, meaning an underestimate of large tree crowns and an over estimate in case of dominated trees. In case of plot level analysis, the correlation intensity between ground and remote sensing data is increasing due to the use of average values per plot, but only in the case of IKONOS imagery. The results are very poor when using aerial photos because of the high off-nadir angle used during the flights. The crown has a side view and the dimension is modified.

There are good results regarding the measurement of density indices: canopy cover index and number of trees per area unit, both in the case of aerial photos and satellite images. The values of the correlation coefficients vary between 0.5…0.65, also statistically significant.

The stand level analysis shows good results for all the parameters taken into account. In case of crown diameter, the average values are very similar, with differences ranging from 0 to 0.2 m. The variability analysis revealed a significant decrease in the variability of data when measuring on satellite images, but the values of the variation coefficients are significantly correlated.

The IKONOS images are becoming more involved in decision support within the forest management due to their high spatial resolution, multispectral character and reduced price. The level of analysis on this type of images can be lowered to a tree level, but with some consequences regarding precision and only after a calibration of the measurement model in similar conditions to the research area. The calibration is very efficient when done on homogeneous stands, stands that could be fully or statistically inventoried. It is important that, in statistical inventory, the sample plots to be representative for the entire stand. In case of biometric parameters variability assessments the interpretation of the results should take into account the decreased variability of the values extracted from satellite images and the necessity of calibrating the model as well.

Acknowledgements. The satellite imagery data was obtained by the courtesy of Vanatory Neamt Vanatori. The image processing and analysis was performed within the Research Project 31-047/2007 DEGRATER "THE CREATION OF A GEOREFERENCED DATABASE IN SUCEAVA PLATEAU BY MONITORING THE DAMAGED SOILS ON DIGITAL IMAGES, AS A DECISION BASE IN ECOLOGICAL IMPROVEMENT" within the program "Partnerships in Priority Domains".

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Received: 28 October 2010. Accepted: 30 October 2010. Published online: 10 November 2010.
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How to cite this article:
Barnoaiea I., 2010 Forest structure analysis on very high resolution images. AES Bioflux **2**(2):239-251.