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PREDICTION OF CONIFEROUS FOREST TREE-SIZE DIVERSITY BASED ON SPECTRAL AND TEXTURE DATA FROM SATELLITE IMAGES

Petar Dimitrov [1]

Tree-size diversity is an important characteristic of forests which is connected with their structural complexity. This study aims to evaluate the relationship between spectral and texture features from SPOT 5 and QuickBird images from the one hand and diversity of trees' diameter and height from the other. Based on ground measurements in a coniferous forest site, four parameters were calculated for the diameter and height: Shannon's index, Range, Diversity, and Coefficient of Variation (CV). From the SPOT 5 spectral bands and six vegetation indices (VIs) the near-infrared band was most strongly correlated with the forest parameters. For all parameters (except CV) correlations were significant (maximal values between –0.74 and –0.85). The QuickBird spectral bands and VIs did not show better correlations compared with the SPOT 5. From the tested texture measures derived from the QuickBird bands the Homogeneity and Dissimilarity were the most correlated with the tree-size diversity parameters (r=0.42 ÷ –0.67). Multiple linear regression equations were compiled for prediction of the Range of diameter and height classes (Adj. R^2=0.86 and 0.81 respectively). These equations allow estimating the Range of diameter and height classes with RMSE of 25% and 21% respectively, as calculated using leave-one-out cross-validation.

Keywords: forest structure, satellite spectral data, SPOT 5, QuickBird, Rila Mountain

ИЗЧИСЛЯВАНЕ НА ПОКАЗАТЕЛИ ЗА РАЗНООБРАЗИЕТО В РАЗМЕРИТЕ НА ДЪРВЕТАТА В ИГЛОЛИСТНИ ГОРИ НА БАЗАТА НА СПЕКТРАЛНА И ТЕКСТУРНА ИНФОРМАЦИЯ ОТ СПЪТНИКОВИ ИЗОБРАЖЕНИЯ

Петър Димитров

Абстракт: Степента на разнообразие по отношение на размерите на дърветата е важен показател за структурата на горските съобщества. Това изследване

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[1] Space Research and Technology Institute – BAS, petar.dimitrov@space.bas.bg

цели да оцени връзката между спектралната и текстурната информация, съдържаща се в изображения от спътниците SPOT 5 и QuickBird, от една страна, и разнообразието в размерите на дърветата (диаметър и височина), от друга. На базата на измервания на височината и диаметъра на дърветата в тестови площадки в район с иглолистни гори са изчислени четири показателя: индекс на разнообразието на *Shannon*, обхват, разнообразие и коефициент на вариация (CV). От данните от SPOT 5, включващи четирите спектрални канала и шест вегетационни индекса, най-висока корелация с изследваните показатели имат данните от близкия инфрачервен канал. При всички показатели, с изключение на CV, корелацията е значима (максимални стойности между –0,74 и –0,85). Данните от QuickBird – спектрални канали и вегетационни индекси – не показват по-добра корелация с показателите за разнообразие в сравнение със SPOT 5. От тестваните текстурни параметри, изчислени на базата на изображението от QuickBird, най-силно корелирани с показателите за разнообразие на размерите на дърветата са *Homogeneity* и *Dissimilarity* (r=0.42 ÷ –0.67). Съставени са множествени линейни регресионни уравнения за изчисляване на показателите обхват на степените на дебелина и обхват на класовете по височина (съответно Adj. R^2=0,86 и 0,81). Изчислената чрез кръстосана валидация грешка на регресионните модели за двата показателя е съответно 25 % и 21 %.

Ключови думи: структура на гората, спътникови спектрални данни, SPOT 5, QuickBird, Рила

INTRODUCTION

The degree of structural complexity is one of the most important characteristics of forests. It has been shown that forest structure interrelates with many ecological processes and is closely connected with forest biodiversity (Stelfox, 1995). Furthermore, the response of forest structure to different management systems and silvicultural treatments is increasingly studied (Sullivan et al., 2001) as the understanding of these relationships is expected to contribute to the sustainable forest management. Therefore, there is growing need for data on different aspects of forest composition and structuring. However, measuring forest structure is not straightforward because it can be defined in various ways and assessed using different measures, both spatial and non-spatial (LeMay, Staudhammer, available online). The three major aspects of forest structure as summarized by Pommerening (2002) are: spatial distribution, species diversity and variations in tree dimensions. Tree dimensions (bole's diameter and height) are commonly inventoried in forestry and their variation can be readily assessed. Therefore, measures of tree-size diversity can be suitable for providing forest managers with forest structure information (Varga et al., 2005).

The Shannon's index (Shannon, Weaver, 1949) is commonly used to describe tree-size diversity (Varga et al., 2005; Boucher et al., 2006). Designed to assess species diversity, the index can be computed by substituting species for classes of diameter at breast height (DBH) or height classes to assess tree-size diversity. Other measures of tree-size diversity are the number of height or diameter classes relative to a potential maximum number in a region (Jakubauskas, 1996) and the coefficient of variation (CV) of individual trees' diameters and heights (Varga et al., 2005).

Remote sensing technique to quantify forest structure in spatially explicit manner would provide ecologist and managers with invaluable information. In the past decades it was shown that remote sensing data have potential to estimate different forest parameters. Tree-size diversity is, however, not among the forest characteristics commonly derived by remote sensing data. This study aims to evaluate the relationship between spectral and texture data from SPOT 5 and QuickBird satellite images from the one hand, and diversity of tree diameter and height from the other hand focusing specifically on coniferous forests.

MATERIALS AND METHODS

Field measurements to evaluate tree-size diversity were made in 32 temporary plots situated in the north-western part of Rila Mountain (SW Bulgaria). The plots had different size (squares with side 5, 10, 20, or 30 m) depending on the stand age and density. Four main conifers form pure and mixed stands in the study region: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst.), Silver fir (*Abies alba* Mill.), and Macedonian pine (*Pinus peuce* Griseb.) (Petkov et al., 1966). At each plot, the species, DBH, and height were recorded for each tree. In some occasions the tree height was not possible to measure using the clinometer because visibility to the tree's top is blocked by adjacent crowns. For trees which height was not measured it was calculated based on their DBH using species-specific height-curves established from the existing measurements from all plots. Coordinates of each plot were measured by GPS. The data were grouped in 25 DBH classes with a width of 4 cm and in 10 height classes with a width of 4 m. Based on these measurements four forest structure parameters were calculated for both diameter and height. The first was the Shannon's index, H', calculated using Eq. 1:

$$H' = -\Sigma[p_i \ln(p_i)] \quad (1)$$

where p_i is the proportion of trees (in number) in the ith DBH or height class compared with the total number of trees (Boucher et al., 2006). As the index value increases, stands tend to be more uneven-sized, whereas a low index value corresponds to a more even-sized stand (Boucher et al., 2006). The maximum value for Shannon's index occurs when the proportions are equal over all classes (Varga et al., 2005). The second parameter was the Diversity of DBH and height classes (D_{div} and H_{div}, respectively) and was calculated in accordance with (Jakubauskas, 1996) as the number of DBH/height classes present in a plot divided by the total number of classes established for the study region (25 and 10 respectively). Similar parameter, the Range of DBH and height classes (D_{range} and H_{range}, respectively) was calculated as the number of classes within the range from the lowest to the highest class in a plot (i.e. including empty classes, if any) divided by the total number of classes possible for the region. The last parameter was the CV calculated using the original non-classified DBH and height measurements.

A Satellite Pour l'Observation de la Terre (SPOT) 5 satellite image from 14 July 2008 was orthorectified, converted to radiances, and terrain corrected for differences in illumination using the SCS+C method (Soenen et al., 2005). The four 10 m spectral bands were used in the study: Green (0.49 – 0.60 µm), Red (0.61 – 0.68 µm), Near Infrared (NIR) (0.78 – 0.89 µm) and Shortwave Infrared (SWIR) (1.54 – 1.75 µm). Six spectral vegetation indices (SVIs) were calculated from the SPOT 5 bands:

- Normalized Difference Vegetation Index (NDVI = NIR – Red / NIR + Red) (Rouse et al., 1974);
- Simple Ratio (SR = NIR / Red);
- Normalized Difference Infrared Index (NDII = NIR – SWIR / NIR + SWIR) (Hardisky et al., 1983);
- Structural Index (SI = NIR / SWIR) (Gerylo et al., 2000);
- Corrected NDVI (NDVIc = NDVI * (1 – (SWIR – $SWIR_{min}$) / ($SWIR_{max}$ – $SWIR_{min}$))) (Nemani et al., 1993);
- Reduced Simple Ratio (RSR = SR * (1 – (SWIR – $SWIR_{min}$) / ($SWIR_{max}$ – $SWIR_{min}$)) (Brown et al., 2000).

For $SWIR_{min}$ and $SWIR_{max}$ the 2nd and 98th percentile of the distribution of values in the SWIR band were used.

The QuickBird multispectral image (16 August 2007) was orthorectified and converted to top of the atmosphere reflectance. The four 2.4 m spectral bands were used in the study: Blue (0.43 – 0.54 µm), Green (0.46 – 0.62 µm), Red (0.59 – 0.71), and NIR (0.71 – 0.91 µm). Four gray-level co-occurrence matrix (GLCM) texture filters were applied to each of the QuickBird bands, namely: Variance, Homogeneity, Contrast, and Dissimilarity. NDVI and SR were also calculated.

The relationships between the satellite variables (band values, SVIs, and texture measures) and the tree-size diversity parameters were examined by calculating the Pearson’s correlation coefficient (*r*). Then the possibility for regression-based prediction of tree-size diversity was tested. Two types of models were used: simple linear regression, with only spectral variable as predictor, and multiple linear regression with both spectral and texture predictor. The accuracy statistics:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \qquad (2)$$

and

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i) \qquad (3)$$

were calculated using the leave-one-out cross validation method, where y_i is the ground-measured value at plot *i*, $\hat{y}_i$ is the predicted value for plot *i* using data from the rest of the plots, and *n* is the number of plots used. The relative counterparts of these statistics – $RMSE_r$ and $Bias_r$ – were calculated as percent from the mean value of the corresponding forest parameter as measured in the plots.

RESULTS

To extract the values of the SPOT 5 spectral bands and SVIs for the corresponding field plots locations the weighted average of the four pixels closest to the plot centre was used. The QuickBird data was averaged over area with 10 m radius around the measured plot centre. In the analysis of the QuickBird data 31 field plots were used because one of the plots was outside the image footprint. The coefficients of correlation of the satellite spectral variables with the tree-size diversity parameters are presented in Tab. 1. Only the coefficient of variation of diameters (D_{CV}) was not correlated ($p>0.05$) with any of the spectral variables. Most of the correlation coefficients for H_{CV} were also insignificant. The Shannon's index, Range and Diversity of DBH/height classes, however showed moderate to strong relationships with the satellite data (Tab. 1). Specifically, high r values were observed for these three parameters and the NIR band of SPOT 5, ranging between -0.74 and -0.85 ($p<0.001$). Similar values were achieved also for NDVI and SR, which were the only SVIs performing well. The indices incorporating the SWIR band were poorly correlated with the tree-size diversity in the study area. The corrected NDVI have been proposed to increase accuracy of LAI (leaf area index) estimates in open canopies where the NIR reflectance is strongly affected by understorey vegetation and background materials (Nemani et al., 1993). Similarly, RSR have been shown to reduce background effects when calculating LAI in coniferous forest (Brown et al., 2000). In our case the SWIR correction factor in these two indices has little effect because all plots are characterised by relatively high canopy closure. From the QuickBird data again the NIR band was most strongly correlated with the tree-size diversity parameters, but the correlations were lower compared to the SPOT 5 NIR band. The difference in performance between the two NIR bands were, however, not significant according to the test for equality of correlation coefficients (the p-values of the test statistic Z calculated in MYSTAT 12 software stayed over 0.169 for all forest parameters).

Scatter plots in Fig. 1 depict the curvilinear form of the relationship between SPOT 5 NIR band and the Range and Diversity of DBH/height classes. The NIR band becomes less sensitive to the two parameters as their values increase. In fact the Range and Diversity parameters behave very similarly which is clear from their correlation coefficients with the spectral data and from the graphics. When continuum of size-classes is present in a plot the values of the Range and Diversity coincide; otherwise the Range is higher than Diversity. The Range of classes was used in this study as a complement to Diversity because it can indicate how different the size-classes present in a plot are. For example, if two plots have the same number of size-classes they will have also the same Diversity; but the Range may differ depending on how close to each other these classes are. However, based on the results in this study, it can not be given preference to one of these parameters at the expense of the other. The Shannon's index for the diameters ($D_{H'}$) showed roughly linear relationship with the SPOT 5 NIR band and highest correlation from all tree-size diversity parameters. The lower saturation effect makes this parameter suitable for remote sensing estimation. One disadvantage is that the values of the Shannon's index are not intuitive. Fig. 1 shows that with decrease of the tree-size diversity radiance detected in the SPOT 5 NIR band increases. This may be explained with the stronger reflectance from the smoother canopies characteristic for most even-aged, structurally simple forest stands. Gaps in old forest and patches of remnant old trees in regenerating forest contribute to spatial and tree-size diversity (Spies, 1998). In such structurally complex forests shadows cast by the canopy are

Table 1

Pearson's correlation coefficients (r) for the tree-size diversity parameters against the SPOT 5 and QuickBird bands and SVIs. The highest coefficient for each forest parameter is highlighted. Only shown are coefficients significant at the 0.05 level

	SPOT 5										QuickBird					
	Green	Red	NIR	SWIR	NDVI	$NDVI_C$	SR	RSR	NDII	SI	Blue	Green	Red	NIR	NDVI	SR
D_{CV}																
D_{div}	–0.71	–0.56	**–0.82**	–0.60	–0.77	–0.36	–0.75	–0.43	–0.45	–0.49	–0.50	–0.59	–0.51	–0.71	–0.53	–0.55
D_{range}	–0.69	–0.55	**–0.81**	–0.59	–0.77	–0.39	–0.75	–0.45	–0.46	–0.50	–0.54	–0.65	–0.55	–0.76	–0.61	–0.61
$D_{H'}$	–0.68	–0.55	**–0.85**	–0.61	–0.79	–0.36	–0.78	–0.44	–0.48	–0.51	–0.43	–0.52	–0.42	–0.71	–0.60	–0.61
H_{CV}			–0.37		–0.36						–0.42	**–0.44**	–0.42	–0.37		
H_{div}	–0.66	–0.54	**–0.79**	–0.59	–0.76	–0.36	–0.73	–0.42	–0.44	–0.47	–0.55	–0.66	–0.57	–0.77	–0.58	–0.57
H_{range}	–0.67	–0.53	**–0.82**	–0.60	–0.79	–0.39	–0.76	–0.45	–0.47	–0.50	–0.60	–0.71	–0.61	–0.81	–0.63	–0.62
$H_{H'}$	–0.60	–0.52	**–0.74**	–0.56	–0.68		–0.67	–0.37	–0.38	–0.41	–0.50	–0.57	–0.48	–0.69	–0.51	–0.52

larger and cause a decrease in the overall spectral response value detected by the satellite sensor (Gerylo et al., 2000). This result is in agreement with (Jakubauskas, 1996) who observed negative correlation between Diversity of DBH classes and reflectance in Landsat TM bands.

The texture measures calculated from the QuickBird image bands had only moderate level of correlation with the tree-size diversity parameters (Tab. 2). There were no single texture measures performing best for all eight forest parameters. However the Homogeneity of the Red band and the Dissimilarity of the NIR band had the highest correlation coefficients with six of the forest parameters. Contrary to this, the Variance and Contrast showed poor or insignificant relationship with the tree-size diversity parameters (Tab. 2). The correlation coefficients ranged between 0.42 (D_{CV}) and -0.67 (D_H). The Shannon's index and the Range of size-classes showed slightly higher correlations compared to the other two tree-size parameters. Generally, the values in Tab. 2 are low and suggest limited potential for regression-based prediction of tree-size diversity using QuickBird texture data alone. However, these are rather preliminary results and more detailed study of the influence of input parameters used in the GLCM texture filters on the relationships with the tree-size diversity parameters is needed.

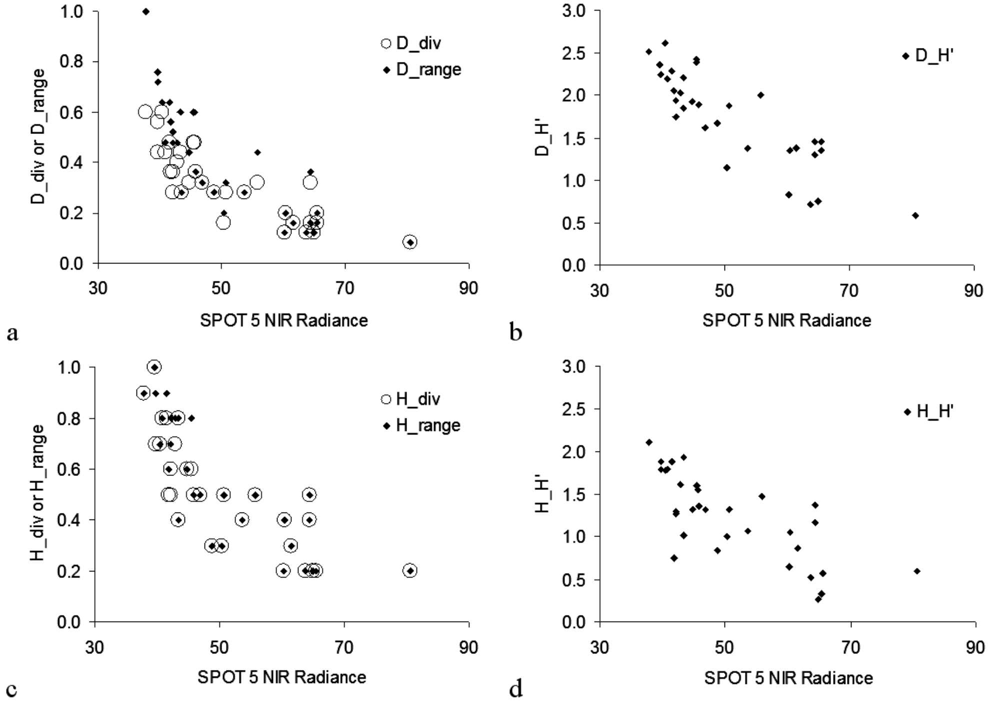

Fig. 1. Scatter plots of SPOT 5 NIR band radiance against the tree-size diversity parameters: a) Range and Diversity of DBH classes; b) Shannon's index for the diameters; c) Range and Diversity of height classes; d) Shannon's index for the heights

T a b l e 2

Pearson's correlation coefficients (r) for the tree-size diversity measures against the QuickBird texture measures. The highest coefficient for each forest parameter is highlighted. Only shown are coefficients significant at the 0.05 level

	Blue band B1				Green band B2				Red band B4				NIR band B4			
	V	*H*	*C*	*D*	*V*	*H*	*C*	*D*	*V*	*H*	*C*	*D*	*V*	*H*	*C*	*D*
D_{CV}															**0.42**	0.41
D_{div}		–0.51	0.42	0.49		–0.59		0.49		**–0.60**		0.39		–0.58	0.45	0.56
D_{range}	0.36	–0.56	0.46	0.53		–0.61		0.51		**–0.64**		0.43	0.37	–0.53	0.47	0.57
$D_{H'}$	0.43	–0.58	0.51	0.56		–0.65	0.39	0.55		**–0.67**		0.48	0.38	–0.62	0.47	0.59
H_{CV}		–0.39		0.38		–0.42		0.38		–0.42			0.38	–0.37	0.56	**0.57**
H_{div}		–0.54	0.44	0.51		**–0.58**		0.46		–0.57		0.36		–0.52	0.46	0.55
H_{range}		–0.57	0.46	0.54		–0.61		0.49		**–0.63**		0.41	0.36	–0.53	0.48	0.58
$H_{H'}$	0.37	–0.52	0.49	0.51		–0.56		0.48		–0.59		0.40	0.41	–0.52	0.52	**0.60**

The texture measures Variance, Homogeneity, Contrast, and Dissimilarity are denoted by the letters *V, H, C*, and *D*.

Table 3

Regression models for the Range of DBH/height classes

	R^2	Adj. R^2	SEE	MSE	F	b	Validation				
							RMSE	$RMSE_r$	Bias	$Bias_r$	Bias sig.
$\log(D_{range}) = b_0 + b_1 * \log(NIR)$	0.795	0.789	0.130	0.016793	116.6	$b_0=4.38957$	0.11	27.5	0.01	2.1	0.671
						$b_1=-2.86640$					
$\log(D_{range}) = b_0 + b_1 * \log(NIR) + b_2 * \log(D_{B4})$	0.867	0.857	0.099	0.009847	91.2	$b_0=3.05112$ $b_1=-2.36259$ $b_2=0.50692$	0.10	24.7	0.01	1.7	0.716
$\log(H_{range}) = b_0 + b_1 * \log(NIR)$	0.733	0.724	0.123	0.015232	82.4	$b_0=3.57499$	0.13	24.2	0.01	1.7	0.690
						$b_1=-2.29384$					
$\log(H_{range}) = b_0 + b_1 * \log(NIR) + b_2 * \log(C_{B4})$	0.821	0.808	0.100	0.010018	64.1	$b_0=2.70142$ $b_1=-2.05404$ $b_2=0.21936$	0.12	21.2	0.01	1.0	0.788

All F and b values are significant ($p<0.000$). In models, DB4 and CB4 denote the Dissimilarity and Contrast from the QuickBird NIR band. SEE – standard error of estimate. MSE – mean square of the residuals. SEE, MSE and b are in transformed units. RMSE and Bias are in the original units.

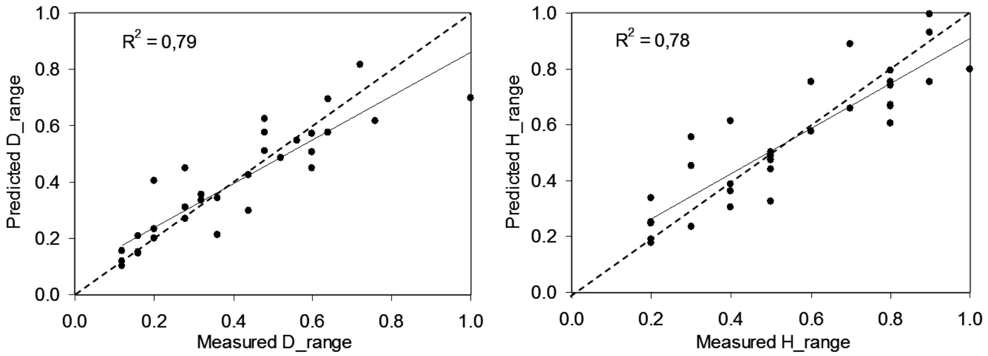

Fig. 2. Scatter plots of D_{range} and H_{range} predictions from the multiple regression models against the ground measured values in the field plots (n=31)

In this study we tested only a limited set of SVIs and texture measures selected for their common use in the literature concerning forest parameters retrieval from remote sensing data. More exhaustive list of spectral and texture variables can certainly be constructed, but for our aims the selected variables give good general overview.

To test the possibility for prediction of tree-size diversity using satellite data the Range was selected as this parameter performed equally well for both diameters and heights. Linear regression analysis was performed, but to account for nonlinearity and heteroscedasticity problems it was needed to apply base-10 logarithm transformation to both y and x variables. After fitting the linear model *y* is back transformed to calculate the validation accuracy statistics. Eq. 4 was used for the multiple regression case:

$$y = 10^{b0} * x^{b1} * x_1^{b2} * 10^{\varepsilon} \qquad (4)$$

where b0, b1, and b2 are the coefficients from the linear fit, and ε is half the mean square of the residuals (MSE/2) (Newman, 1993). Simple linear regression models were constructed using the SPOT 5 NIR band as explanatory variable. We hypothesised that combination of spectral data from SPOT 5 and texture data from QuickBird would provide the best option for prediction of studied forest parameters with this satellite dataset. Therefore, multiple regression models were also tested with the SPOT 5 NIR band included by default and the second predictor chosen among the QuickBird texture measures which were significantly correlated with D_{range} and H_{range}. Selection was made based on the adjusted R^2 value and the significance of the coefficients of the regression equation. The models and their accuracy assessment statistics are presented in Tab. 3. The inclusion of texture measure as a second predictor increased the adjusted R^2 compared to the simple models. This suggests that texture images may be important for constructing more accurate prediction models for tree-size diversity and when available can be used as complement to the spectral images. The multiple regression equations allow estimating the Range of diameter and height classes with RMSE of 25% and 21% respectively. This means an average prediction error with a magnitude of three classes for the Range of DBH classes and one class for the Range of height classes. The Biases of predictions were not significant (Tab. 3). The scatter plots in Fig. 2 show that there is generally good agreement between predicted and measured values of the Range of DBH/height classes.

DISCUSSION AND CONCLUSIONS

The calculated values for the Shannon's index, Range, and Diversity of DBH/height classes are dependent on the selected class width. Therefore, they cannot be compared between different regions and studies unless the same maximal number and width of classes have been used and this hinders their wider usage. However, for a particular study their relative values depict the variations in the structural complexity of forest. Mapped over a region of interest using satellite image data these parameters would provide valuable insight on forest conditions. Estimating the Range and Diversity in numbers, instead of in proportions, and adoption of common tree-size classification may further facilitate the usage of these forest parameters for forest structure characterisation.

The Shannon's index, Range, and Diversity of DBH/height classes are well correlated with the NIR band of SPOT 5 and have potential for regression based prediction. The highest correlation was observed for the Shannon's index of diameters ($r=-0.85$). None of the SVIs used in this study provided further enhancement of spectral information usable for tree-size diversity assessment. The texture measures calculated from the QuickBird bands were not strongly correlated with tree-size diversity parameters. However they provide additional spatial information which may improve the NIR-derived regression predictions.

Calculation of CV does not involve arbitrarily classified size classes and is considered an objective measure of tree-size diversity (Varga et al., 2005). Unfortunately in this study it was not possible to predict D_{CV} and H_{CV} from satellite data because of the insignificant correlations. It may be concluded that the coefficient of variation is not suitable for remote sensing assessment of tree-size diversity, at least for the studied forest type. Shannon's index and the Range and Diversity of DBH/height classes, however, have more potential for remote sensing estimation and mapping. Further studies should concentrate more on these or similar parameters, in order to fully exploit the potential of satellite images for provision of forest structure information in regional to local scale.

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