SHORT COMMUNICATION

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ESTIMATION OF SOME STAND PARAMETERS USING DIGITAL AERIAL PHOTOGRAPHS FOR CONSERVATION AND SERVICE ORIENTED FORESTS

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Forest inventory, which is the first step of forest management planning, is the most difficult stage that requires much time and a lot of efforts. To reduce fieldworks that are considered time consuming and expensive methods of ground measurements, remote sensing data are widely used. Aerial photographs have been an integral part of forest inventory data in Turkey since 1963. Panchromatic and RGBI (Red, Green, Blue, Infrared) aerial photographs acquired by digital aerial cameras proved to be very important in forest inventory. They have maintained their importance for forest management planning process. The aim of this study is to construct a fast and practical inventory model that requires least fieldwork for forest management planning process. Pixel values and vegetation indices (NDVI, DVI, IPVI, RVI and PCA), obtained from remote sensing data, and stand parameters (stand volume, volume increment and number of trees) have been compared statistically. Black pine *Pinus nigra* J. F. Arnold plantations located in the south-east region of Turkey, Çelikhan Forest Planning Unit, was chosen as a research area. 0.5 meter spacing and 8 bit radiometric resolution Ultracam-X Digital Aerial Photos were used as remote sensing data. According to statistical analysis, IPVI and Green Band values provided the highest evaluation coefficient compared to the models developed for the estimation of stand parameters. Adjusted R square of stand volume, volume increment and the number of tree in the models were found to yield 0.74, 0.73 and 0.50 respectively. It was concluded that stand characteristics estimated by statistical models can be used for forest areas managed for conservation and service purposes.

Keywords: *forest inventory, forest management planning, vegetation indices, stand parameters.*

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INTRODUCTION

Forest management planning process starts with forest inventory, which is quite laborious and time-consuming. But up-to-date and reliable information is of great importance for efficient management of forest resources (Schreuder et al., 1993; Forest inventory…, 2006). At present fieldworks are a common information source in today's forest resources inventory used by forest resource planners.

To minimize fieldworks, which is an expensive method of forest inventory, remote sensing data are widely used. In Turkey, combined inventory methods that evaluates aerial photographs and fieldworks together, have been used since 1963 in order to separate stand types and to estimate tree wealth more reliably and accurately (Eler, 2001). Nowadays, digital photogrammetry can be used to obtain panchromatic images with digital aerial cameras and quad band images, namely RGBIR (Red, Green, Blue, and Infrared). This new trend of processing multiband digital aerial photographs offers great advantages for researchers in forest inventory studies (Köhl et al., 2006). For the last fifty years, aerial photos have been an indispensable component of forest inventory (Nelson, 2005).

Numerous studies indicated that there exist empirical relationships between the terrestrial measurements and parameters obtained from remote sensing data. Pixel values and vegetation indices are widely used to generate models across the globe (Hyyppä et al., 2001, 2004; Bohlin et al., 2012; Järnstedt et al., 2012; Nurminen et al., 2013). Based on remote sensing data, forest inventory studies are carried out to develop forest management planning. Aerial photographs along with satellite images and new LiDAR data are widely used for these studies. In Turkey, many researchers applied satellite images of different resolutions in order to estimate the stand parameters. However, there is no study carried out with effective using of aerial photographs.

Our study is aimed at examining the prospects of estimating forest stand parameters for black pine *Pinus nigra* J. F. Arnold plantations located in Çelikhan Forest Planning Unit in the south-east of Turkey. The parameters used were the stand volume, volume increment and number of trees and they were estimated using Ultracam-X digital aerial photographs. First, stand parameters were calculated from the fieldwork data. Next, vegetation indices and pixel values obtained from high resolution aerial images were used to estimate stand parameters utilizing linear regression analysis. Finally, estimation accuracy of the model was evaluated using adjusted R^2 and root mean square error.

MATERIALS AND METHODS

Study area. The study area was located in the Adıyaman State Forest Enterprise, Çelikhan Planning Unit, bounded by 37°56′29″ – 38°10′43″ N, and 38°04′43″ – 38°33′58″ E (Fig. 1).

Field and remote sensing data. The fieldworks were conducted during the summer season of 2013. On the whole, 32 sample plots were selected based on stand types. During field works GPS devices were used to identify the coordinates of the center of each sample plot. In each plot all the trees with diameter at breast height (DBH) more than 7.9 cm were identified and measured at DBH. Also, at least for 3 trees, number of annual growth rings for the last 10 years, bark thickness and tree height were measured to determine volume and volume increment. Forest characteristics of sample plots such as forest type, average age etc. were, in general, identical as it is a plantation forest. However, the characteristics of the stands, such as basal area, tree height etc., vary due to differences in the site quality.

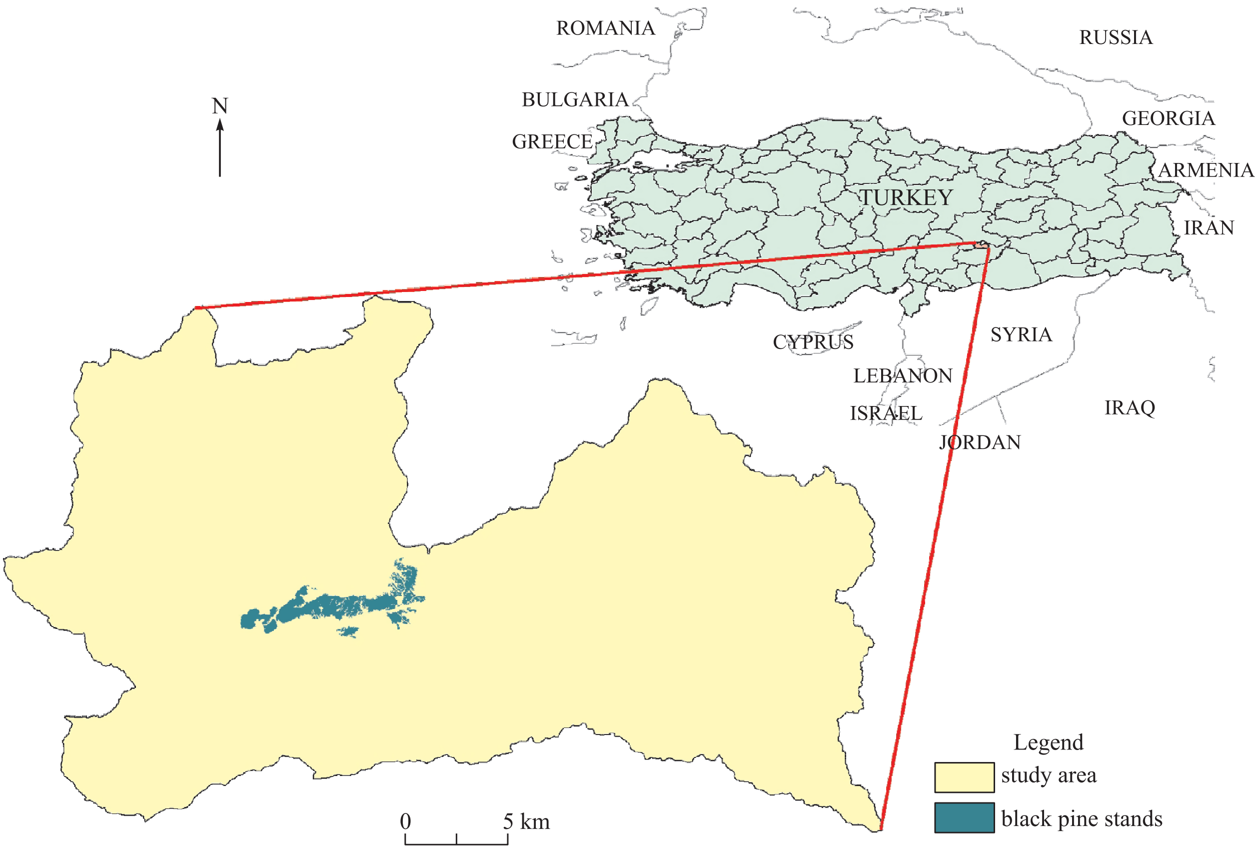

Fig. 1. Study area.

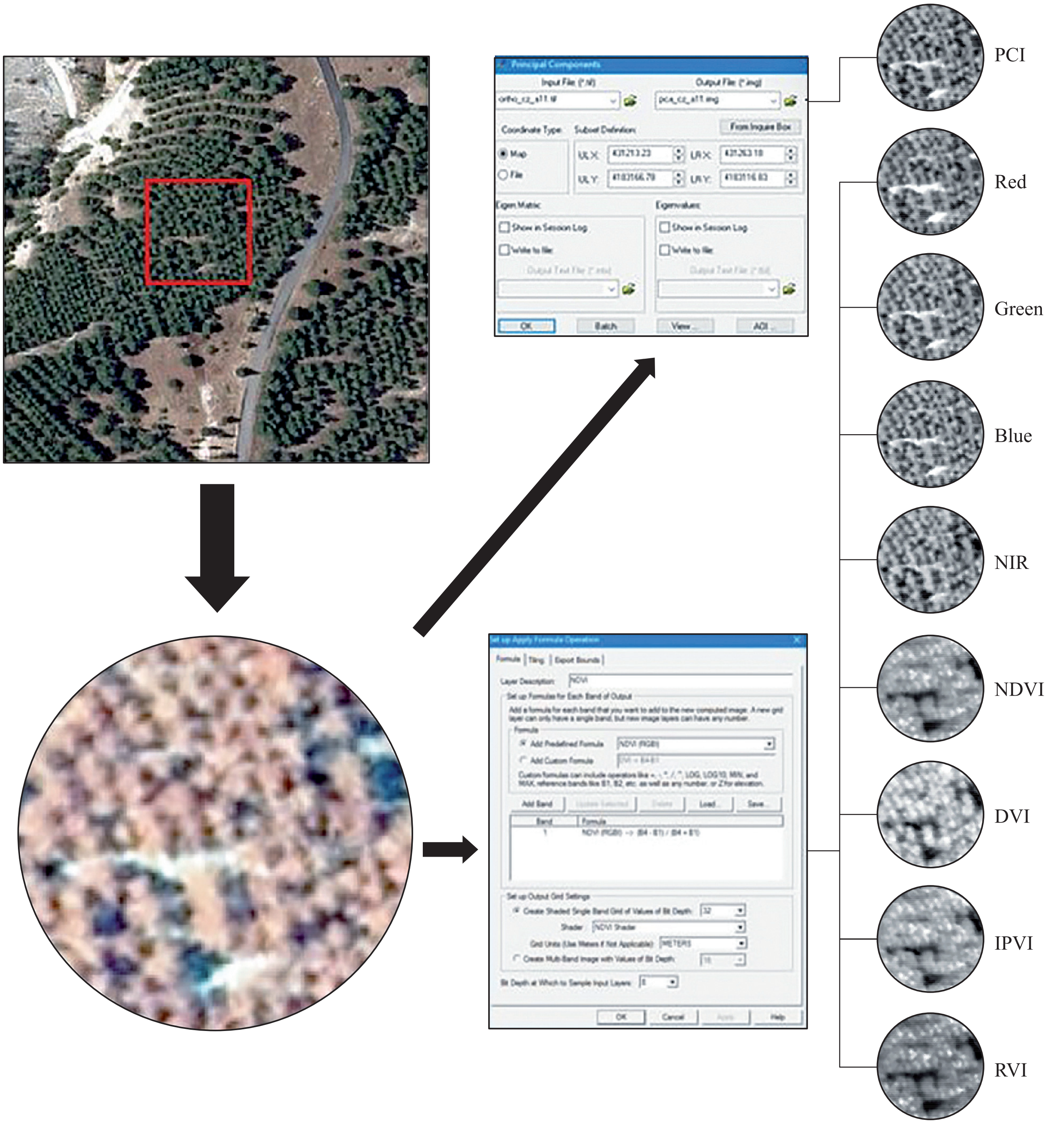

Fig. 2. Vegetation indices and other semantic data obtained with Ultracam-X.

Total area of the plot is 66 123.6 and 792 ha of it are covered by black pine plantations. Other forested areas are mainly poorly managed coppice oak forests. Elevation ranges are between 650 and 2605 m.

Stand volume per hectare (*V*), volume increment per hectare (*I*) and number of trees per hectare (*N*) were calculated using volume equation derived by Erkan (1997).

Ultracam-X data of very high resolution and used as remote sensing data were obtained in 2012. The images have four spectral bands with 0.5 m spacings and 8 bit radiometric resolution. Images were rectified on LPS module of ERDAS 2014 using interior and exterior orientation parameters and digital elevation model. Image windows were provided using the Ultracam-X data with coordinates of the center of the sample plot areas. Then pixel values for each band and principal components (PCA) were obtained by means of ERDAS and also vegetation indices were found with Global Mapper v. 16 (Fig. 2).

Table 1. Determination of vegetation indices

Vegetation Indices	Equations	References
NDVI	(NIR – Red)/(NIR + Red)*	Rouse et al., 1974
DVI	NIR – Red	Clevers, 1988
IPVI	NIR/(NIR + Red)	Crippen, 1990
RVI	NIR/Red	Jordan, 1969

Note. * NDVI – Normalized Difference Vegetation Index; DVI – Difference Vegetation Index; IPVI – Infrared Percentage Vegetation Index; RVI – Ratio Vegetation Index; NIR – Near Infrared Band.

Vegetation indices used in this study and their formulas are presented in Table 1.

Statistical analysis. The statistical relationships between all stand parameters (V, I, N) and the parameters (pixel values and vegetation indices) obtained from the aerial photographs were investigated for the study area. The Kolmogorov-Smirnov test was used to control data set suitability for normal distribution. For $p < 0.05$ all the data sets were adequately distributed. A correlation matrix was used to select independent variables. The regression analysis has been completed using SPSS v. 23. The dependent variables were stand parameters and independent variables were the parameters obtained from aerial photographs for regression analysis. The estimation model was written as:

$$SP = \beta_0 + \beta_1 X_1 + \epsilon,$$

where SP are stand parameters (stand volume, volume increment and number of trees), X_1 is independent variable corresponding to aerial photograph, and the combination variables β_0 and β_1 represent model coefficients and ϵ is the additive error. The estimation results were checked by comparing the estimated stand parameters with the actual values based on field measurements. The reliability of the estimates was measured by means of standard error ($RMSE$) method written as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{pre,i})^2}{n}},$$

where n is number of observations, and $X_{obs,i}$ and $X_{pre,i}$ are the observed and predicted values of parameters.

RESULTS AND DISCUSSION

In this study V, I, and N were estimated using linear regression analysis with pixel values and vegetation indices obtained from 0.5 m and 8 bits resolution aerial photographs. Firstly, correlation analysis was performed to determine the correlation between stand parameters and remote sensing data (Table 2).

Table 2. Correlation analysis results

Vegetation indices	V	I	N
Red	–0.853	–0.856	–0.709
Green	–0.840	–0.858	**–0.756**
Blue	–0.389	–0.456	–0.536
NIR	0.502	0.475	0.316
NDVI	0.864	0.862	0.698
DVI	0.864	0.854	0.675
IPVI	**0.879**	**0.878**	0.713
RVI	0.860	0.870	0.747
PCA	–0.735	–0.757	–0.678

Generally, vegetation indices have the higher correlation compared to pixel values for stand parameters. As performance criteria, $RMSE$, S_{yx} and R^2_{adj}, were used to compare regression models. The best models selected according to the criteria are shown in Table 3.

Independent values were selected according to the correlation results. The variable showing the highest absolute value was chosen for regression analysis. To estimate stand volume and volume increment, IPVI indices were taken for regression analysis. Also for the value of the number of trees, green band of image was selected as an independent variable. All estimation models are valid at probability value of 95 percent ($p < 0.05$).

Taking the above consideration into account, Özdemir (2008) applied pan-sharpened Quickbird image. This study regression model was generated between stem volume and tree attributes obtained from remote sensing data in a mixed forest areas ($R^2 = 0.67$). Elsewhere, Ozdemir and Karnieli (2011) analyzed the relation between stand volume, basal area, the number of trees, and texture values obtained from World View-2 image in drylandforest region with R^2 values 0.42, 0.54 and 0.38 respectively. Günlü et al. (2013) analyzed the estimation

Table 3. Results and performance of regression analysis

Dependent variables	Independent variables	Coefficient of independent variables	*t* statistical values	*P* value	R^2_{adj}	$^*S_{yx}$	*RMSE*
Stand volume, m^3/ha	Constant	112.624	–4.211	0.000	0.74	9.364	14.35 m^3/ha
	IPVI	242.702	5.707	0.000			
Volume increment, m^3/ha	Constant	–7.294	–3.761	0.000	0.73	0.655	1.04 m^3/ha
	IPVI	16.857	5.467	0.001			
Number of trees, stems/ha	Constant	1535.688	7.106	0.000	0.50	139.494	206 trees/ha
	Green Band	–12.439	–3.697	0.001			

Note. $^*S_{yx}$ is an indicator that measures the reliability of the estimating equation like RMSE. S_{yx} shows standard error of the estimation model.

of the number of trees, basal area and stand volume using vegetation indices obtained from Landsat ETM+ data. According to this study, the R^2 values were found to give 0.408, 0.579 and 0.530, respectively. Çil (2014) performed a multiple regression analysis to estimate basal area, stand volume and number of trees using multiple data sources (Landsat 8, Rasat, Göktürk-2, WorldView-2 and digital aerial photographs). The highest R^2 values attained were 0.49, 0.50 and 0.27, respectively. The studies were also conducted, using aerial photographs to estimate stand parameters. Bohlin et al. (2012) analyzed aerial images to estimate tree height, stem volume and basal area, with the adjusted R^2 values amounting to 0.86, 0.72 and 0.78, respectively.

CONCLUSION

In this study we have developed the estimation models for stand volume, volume increment and number of trees using vegetation indices and pixel values obtained from aerial images. Linear regression models were constructed and the performance of the models evaluated. The results indicated that aerial images are of importance to estimate stand parameters for black pine plantations in Çelikhan Forest Planning Unit, in the south-east of Turkey. If for some reasons it is impossible to reach sample plots for some reason (e. g., security problems or economic constraints), this method can be used to generate forest management plans for conservation and service oriented forests. Since in the forestry of Turkey, conservation and service oriented forests do not need high accuracy for stand parameters, it is concluded that the estimation of stand parameters using aerial images can be applied for conservation and service oriented forest areas. In future, additional studies should be made in forest plantation areas in Turkey to refine this method of forest inventory.

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ОЦЕНКА НЕКОТОРЫХ ПАРАМЕТРОВ НАСАЖДЕНИЙ ЗАЩИТНЫХ И РЕКРЕАЦИОННЫХ ЛЕСОВ С ИСПОЛЬЗОВАНИЕМ ЦИФРОВЫХ АЭРОСНИМКОВ

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Лесная таксация, являющаяся первым шагом в процессе лесоустройства, представляется наиболее сложным этапом, требующим наибольших затрат времени и усилий. С целью сокращения объема полевых работ, включающих трудоемкие и дорогостоящие методы наземных измерений, в современной практике лесной таксации широко используются данные дистанционного зондирования. В Турции с 1963 г. используются аэрофотоснимки в качестве важного компонента инвентаризации лесов. Панхроматические и спектрозональные (RGBI – Red, Green, Blue, Infrared) аэрофотоснимки, полученные современными цифровыми аппаратами, обеспечивают преимущества при таксации леса. Они сохранили свое значение в процессе планирования лесопользования. Цель настоящего исследования – разработать быструю и практичную модель инвентаризации лесов с меньшим объемом дорогостоящих полевых работ при лесоустройстве. Статистически сопоставлены значения пикселей и индексы растительности (NDVI, DVI, IPVI, RVI и PCA), полученные по аэроснимкам, и параметры объема древесины, ее прироста и количества деревьев. В качестве объекта исследований выбраны насаждения плантаций сосны черной *Pinus nigra* J. F. Arnold, расположенные в юго-восточной части Турции, в Целиханском лесничестве (Çelikhan Forest Planning Unit). В работе использованы цифровые аэрофотоснимки с пространственным разрешением 0.5 м, 8-битного радиометрического диапазона, полученные аэрофотоаппаратом Ultracam-X. По результатам проведенного статистического анализа наибольшие индексы детерминации в определении параметров насаждений по аэрофотоснимкам получены в режиме IPVI, в зеленом диапазоне длин волн (Green Band). Уточненные индексы детерминации в определении по снимкам объема древесины, прироста запаса и количества деревьев составили 0.74, 0.73 и 0.50 соответственно. Результаты исследований показывают, что таксационные параметры насаждений, определенные с использованием статистических моделей и данных дистанционного зондирования, могут быть использованы при устройстве и ведении хозяйства в защитных и рекреационных лесах.

Ключевые слова: *лесная таксация, лесоустройство, вегетационные индексы, параметры насаждений.*