Modeling Some Stand Parameters Using Vegetation Indices Based on Landsat ETM+ in Ayancık-Goldag Planning Unit, TURKEY

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Abstract:
Forest inventory data are needed for ecological, economic and social values of forest and all stages of forest management planning. Conventionally, forest inventory data has been collected primarily through field survey, which is expensive and time-consuming. However, remote sensing data has played a significant role in forestry studies for several decades, especially as a tool for obtaining about the forest inventory in large forest areas. Forest resource monitoring with Landsat TM and other moderate resolution sensors is a crucial module of a wide variety of forest applications. The attractiveness of Landsat data can be qualified to several basic characteristics of the Landsat satellite data, including low imagery costs and free data distribution facilitate widespread use a spatial resolution enough to characterize typical forest cover dynamics related to forest management. This study assessed the suitability of Landsat TM some vegetation indices for predicting forest stand parameters in northern Turkey. The empirical relationships between the forest stand parameters such as stand volume, basal area and tree density, and Landsat TM satellite image were obtained using stepwise multiple regression analysis. The results indicated moderate relationships (except for tree density) between stand parameters of forest and Landsat TM satellite image. The adjusted R² values from the regression analysis using the vegetation indices for stand volume, basal area and tree density were found to be 0.530, 0.579 and 0.408, respectively.

Key Terms: Landsat TM satellite image, stand parameters, regression models, vegetation indices.

Introduction:
Forest stand parameters such as stand volume, basal area, height, tree density and average tree diameter are essential documents required to assess forest resources and forest management planning (Zimble et al. 2003). Generally, the forest stand parameters aforementioned have been collected ground measurements using temporary sample plots. Even though this method offers highly precise measurement of forest stand parameters, it is time-consuming, expensive and often unfeasible (Trotter et al. 1997). Several investigators have suggested that remote sensing data can be studied as a method of collecting about forest stand parameters (Wulder 1998; Hyppa et al. 2000; Lu et al. 2004). Lately, remote sensing researches have indicated that prediction of forest stand parameters using satellite data has focused on empirical relationships established between the ground measurement and satellite data like band reflectance values and vegetation indices (Rouse et al. 1974; Tucker 1979; Spanner et al. 1990; Brown et al. 2000; Leyk et al. 2002). In this connection, the aim of this study is to examine the capability of Landsat TM various vegetation indices to estimate forest stand parameters such as stand volume, basal area and tree density in the northern Ayancık-Goldag planning unit, Turkey.

Material and Methods

Study Area: The research area was the Goldag forest planning unit with 600 ha, a part of Sinop-Ayancık province located in the central Black Sea Region, Turkey (647000-650000 E. 4629000-4632000 N. UTM ED 50 datum Zone 36 N, Figure 1). Elevation ranges from 500 m to 970 m with an average of 775 m. The research area is situated on a steep terrain, topographic surface with a slope ranging from 10% to 60%, with an average of 26%. Average annual temperature reaches a maximum of 27.6°C in the summer and a minimum of 13.8°C in the winter with an average annual temperature of 17.6°C. Average annual precipitation in the study area is 677.3 mm. Generally, soils tend to be heavy clay type. The study area is covered with unmanaged, even-aged, pure stands of oriental beech (Fagus orientalis L.).
Material:

In this study, the ground measurements were collected from 70 sample plots, which location was obtained from forest inventory distributed by 300x300 m grids in August 2005. The size of sample plots ranged from 400 m$^2$ to 800 m$^2$. The restrictions of each sample plot were positioned using ground control points and a Global Positioning System (GPS) device. In each sample plots, details of all trees with a diameter greater than 7.9 cm at breast height were taken. Stand height (to the nearest 0.1 m with digital hypsometer in randomized sub-sample), and diameter at breast height (DBH) were measured. The volume in sample plots was estimated using a local volume table, containing DBH. Finally, the volume per hectare (m$^3$ ha$^{-1}$) was estimated using the total volume of all trees in each sample plot. In addition, the tree density was computed by counting the trees in each plot. Basal area (m$^2$ ha$^{-1}$) was calculated using the dendrometric formula.

Satellite image processing and development vegetation indices:

Data processing, interpreting and analysis were performed using Erdas Imagine 9.1$^\text{TM}$ version (Erdas, 2002). In this study, one satellite image was used to remote sensing data medium spatial resolution Landsat ETM+ acquired on May 3, 2000. The Landsat ETM+ data orthorectified, and geo-referenced using 1/25.000 scale Topographical Maps with UTM projection (ED 50 DATUM, Zone 36) using first order nearest neighbor rules. A total of 24 ground points were used to register the ETM+ image subset a rectification error less than 1 pixel image. Solar zenith angle and atmosphere influence spectral value of satellite image. Thus, radiometric correction must be done to convert digital number to reflectance value. In the process of radiometric correction, the digital number of Landsat ETM+ must be converted to radiance value, and then to reflectance. The information for the coming radiometric correction (solar zenith angle, acquisition date and so on) can be obtained from Landsat ETM+ ancillary data.

Calculating vegetation indices:

In this study, Landsat ETM+ data was used to produce ten vegetation indices such as NDVI, SR, DVI, SAVI, NDS3, NDS4, NDS7, ND32, ND73 and EVI. The vegetation indices formulas and references for these indices were shown in Table 1.
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Table 1. Definition of vegetation indices used in the study area

<table>
<thead>
<tr>
<th>Vegetation indices</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDVI</td>
<td>( \text{NIR} \cdot \text{Red}/\text{NIR} + \text{Red} )</td>
<td>Rouse et al. (1974)</td>
</tr>
<tr>
<td>SR</td>
<td>( \text{NIR}/\text{Red} )</td>
<td>Jordan (1969)</td>
</tr>
<tr>
<td>DVI</td>
<td>( \text{NIR} \cdot \text{Red} )</td>
<td>Clevers (1988)</td>
</tr>
<tr>
<td>SAVI</td>
<td>( \frac{(\text{NIR} \cdot \text{Red}) \cdot (1+L)}{\text{NIR} + \text{Red} + L} )</td>
<td>Huete (1988)</td>
</tr>
<tr>
<td>ND53</td>
<td>( \text{MID} \cdot \text{Red}/\text{MID} + \text{Red} )</td>
<td>Lu et al. (2004)</td>
</tr>
<tr>
<td>ND54</td>
<td>( \text{MID} \cdot \text{NIR}/\text{MID} + \text{NIR} )</td>
<td>Lu et al. (2004)</td>
</tr>
<tr>
<td>ND57</td>
<td>( \text{MID(TM5)} \cdot \text{TMC7}/\text{MID} + \text{MID} )</td>
<td>Lu et al. (2004)</td>
</tr>
<tr>
<td>ND32</td>
<td>( \text{Red} \cdot \text{Blue}/\text{Red} + \text{Blue} )</td>
<td>Lu et al. (2004)</td>
</tr>
<tr>
<td>ND73</td>
<td>( \text{MID(TM7)} \cdot \text{Red}/\text{MID} + \text{Red} )</td>
<td>Sivanpillai et al. (2006)</td>
</tr>
<tr>
<td>EVI</td>
<td>( \text{NIR} \cdot \text{Red}/(\text{NIR} + (1 \cdot \text{Red}) \cdot (1 + \text{Blue}) \cdot (1 + L)) )</td>
<td>Huete et al. (1999)</td>
</tr>
</tbody>
</table>

ND, normalized difference; NDVI, Normalized Difference Vegetation Index; SR, Simple ratio; SAVI, Soil Adjusted Vegetation Index; DVI, Difference Vegetation Index; EVI, Enhanced Vegetation Index; VIS, visible wavelengths (red, green, blue); NIR, near infrared wavelengths (ETM 4); MID, middle infrared wavelengths (ETM 5, ETM 7).

Statistical Analysis:

To examine and model the relationships between vegetation indices and forest stand parameters such as stand volume, basal area tree and density the stepwise multiple linear regression analysis were used. The stepwise multiple regression models were developed to estimate the models for the estimation of forest stand parameters using vegetation indices and their combination as independent variable. The dependent variables were forest stand parameters, e.g. stand volume, basal area and tree density. In modeling approach, the regression models were developed to estimate forest stand parameters as a function of suite of remote sensing data variables gathered in studied forest site. The multiple stepwise regression analysis was performed using SPSS version 15.0 (SPSS Institute Inc 2007). The stepwise regression technique was used to select the best site variables that are significant (p<0.05) with determination of the highest value of coefficient adjusted by number of parameters \( R^2_{adj} \), also called adjusted the coefficient of determination. In this study, the following linear relationship was assumed:

\[
\ln(\text{SP}) = \beta_0 + \beta_1 \cdot X_1 + \beta_2 \cdot X_2 + \ldots + \beta_n \cdot X_n + \varepsilon \tag{1}
\]

where SP is the forest stand parameters, e.g. stand volume, basal area and tree density, \( X_1 \ldots X_n \) are variable vectors corresponding to vegetation indices variables, \( \beta_1 \ldots \beta_n \) represent model coefficients and \( \varepsilon \) is the additive error term (Corona et al. 1998, Fontes et al. 2003). The regression models were evaluated based on the accuracy statistics. The accuracy statistics covered the absolute and relative biases and the root mean square error (RMSE and RMSE %). These statistics were calculated for the models as follows: (Eq. 2-5).

\[
\text{bias} = \frac{\sum (y_i - \hat{y}_i)}{n} \tag{2}
\]

\[
\text{bias} % = 100 \left( \frac{\sum (y_i - \hat{y}_i)}{\frac{\sum \hat{y}_i}{n}} \right) \tag{3}
\]

\[
\text{RMSE} = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-1}} \tag{4}
\]

\[
\text{RMSE} % = 100 \left( \frac{\sqrt{\sum (y_i - \hat{y}_i)^2}}{\frac{\sum \hat{y}_i}{n}} \right) \tag{5}
\]

Where \( n \) is the number of observations, and \( y_i \) and \( \hat{y}_i \) are observed and predicted values of forest stand parameters e.g. stand volume, basal area and tree density from developed models.
Results and Discussions:

The selected best regression subgroup models, accuracy statistics, e.g. the coefficients of determination ($R^2$) and the standard error of model (Sy.x) the error estimates of attributes for each forest stand parameters are presented in Tab. 2 for the vegetation indices. In these selected subgroup regression models for forest stand attributes, the F statistics and coefficients were significant at a probability level of 95 percent ($p<0.05$). The best predictive models based on the independent variables including Landsat ETM+ vegetation indices have accuracy statistics with the adjusted $R^2=0.530$ for stand volume, with the adjusted $R^2=0.579$ for basal area and with the adjusted $R^2=0.408$ for tree density.

Table 2. Parameters of the ‘best fit’ regression models of some forest stand parameters based on the vegetation indices

<table>
<thead>
<tr>
<th>Model Group</th>
<th>Dependent Variables</th>
<th>Independent Variables</th>
<th>Coefficients of Independent Variables</th>
<th>S.E. of Variables</th>
<th>t-statistics</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree density</td>
<td>Ln(N)</td>
<td>Constant</td>
<td>5.252</td>
<td>0.337</td>
<td>15.574</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ND53</td>
<td>-20.319</td>
<td>5.340</td>
<td>-3.805</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ND57</td>
<td>22.917</td>
<td>5.781</td>
<td>3.964</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ND73</td>
<td>18.507</td>
<td>4.643</td>
<td>3.986</td>
<td></td>
</tr>
<tr>
<td>$R^2=0.408$</td>
<td>Sy.x=0.15124</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal area</td>
<td>Ln(BA)</td>
<td>Constant</td>
<td>4.755</td>
<td>0.399</td>
<td>11.907</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DVI</td>
<td>0.021</td>
<td>0.004</td>
<td>5.909</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAVI</td>
<td>-4.216</td>
<td>0.781</td>
<td>-5.402</td>
<td>0.000</td>
</tr>
<tr>
<td>$R^2=0.579$</td>
<td>Sy.x=0.12664</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand volume</td>
<td>Ln(V)</td>
<td>Constant</td>
<td>6.427</td>
<td>0.163</td>
<td>39.335</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nd32</td>
<td>6.459</td>
<td>1.131</td>
<td>5.708</td>
<td>0.000</td>
</tr>
<tr>
<td>$R^2=0.530$</td>
<td>Sy.x=0.17942</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$R^2_a$; Adjusted coefficient of determination, Sy.x.; Standard error for models

In this study, the regression models were employed for establishing models between the forest stand parameters and vegetation indices obtained from Landsat ETM+ satellite image. The model based on ND32 as independent variables the best predictor of stand volume with adjusted $R^2=0.530$; the model depend on DVI and SAVI explained the basal area with adjusted $R^2=0.579$. The model based on ND53, ND57 and ND73 as independent variables the best predictor of tree density with adjusted $R^2=0.408$.

Landsat satellite image have been found to be significant predictors stand volume, basal area, tree density in other studies depend on correlation, regression and other statistical analyses (Zheng et al., 2004; Hall et al., 2006; Mohammadi et al., 2010; Grahramany et al., 2012). Hall et al. (2006) investigated the possibility of estimation of stand volume using Landsat data. The model for stand volume was obtained an adjusted $R^2=0.71$. Sivanpillai et al. (2006) analyzed the estimation of stand age and tree density using Landsat data. They indicated that Landsat data has potential for predicting the stand age and tree density ($R^2=0.78$ and $R^2=0.60$), respectively. Mohammadi et al. (2010) modelled stand volume and tree density using Landsat ETM+ data. The models for tree density and stand volume were obtained with an adjusted $R^2=0.73$ and $R^2=0.43$, respectively. Poulain et al. (2010) modelled the basal area using Aster data in Nothofagus pumilio forest areas. The models for the basal area was obtained with and adjusted $R^2=0.72$. Gebreslasie et al., (2010) analyzed the prediction of stand volume and basal area. The models for stand volume and basal area were founded with an adjusted $R^2=0.67$; $R^2=0.51$, respectively. Grahramany et
al. (2012) analyzed the relationships between basal area with SPOT-5 data in western forests. SPOT-5 data were able to estimate basal area with R²=0.62. Günlü et al. (2012) modelled the stand volume using Landsat TM satellite data in Buyukduz planning unit located in Karabuk city in the northwestern part of Turkey. The models for the stand volume was obtained with and adjusted R²=0.54.

Conclusions:

This study examined the relationships between some vegetation indices recorded by the Landsat ETM+ and aforementioned forest stand parameters over northern Turkey were analyzed through regression analysis. Results from these analyses indicated that the vegetation indices obtained from Landsat TM satellite data are useful (except for tree density) for the prediction aforementioned forest stand parameters in northern of Turkey.

References


