SPECTRAL MIXTURE MODELING TO ESTIMATE WOOD VOLUME IN NORTH OF SPAIN FROM OPTICAL SATELLITE DATA

MAPEAMENTO DE VOLUME EM POVOAMENTO DE CONÍFERAS USANDO A MISTURA ESPECTRAL DE IMAGENS TM/LANDSAT

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ABSTRACT

Information from satellite imagery is an important data source to forest management. Remote sensing techniques provide information about volume, biomass and other biophysical parameters of forest stands. The main goal of this work is to map the conifer stand volume from Landsat Thematic Mapper (TM) data using Spectral Mixture Analysis (SMA). Fraction images from spectral unmixing show biophysics properties more easily than original bands because they represent physics aspects of ground covers. The work area was El Alto Valle del Ebro (Spain). Two mini-scenes, (50x50km) acquired on March 12th 1996 and July 13th 1996, were used. The applied methodology had three main steps: 1) unmixing the original imagery, the bands 3, 4, 5 and 7 (the most employed in vegetation studies) were used in SMA; 2) these fraction images were related with the over bark volume (OBV) variable (extracted from Second Spanish National Forest Inventory NFI2) by means of regression techniques and multivariate analysis; 3) a volume map was obtained using interpolation techniques from the obtained allometric model

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and the basal area (BA), of considered stand. The main conclusion of this work was the possibility to obtain a model (adjusted R^2=0.75) which permitted to estimate the stand volume from medium spatial resolution satellite data. Moreover, the use of this model and with the support of digital ortophotographs allowed an estimated volume map to be obtained.

Key words: Forest inventory; remote sensing; conifer stand; volume mapping; unmixing

RESUMO

Informação advinda de imagens de satélite é uma importante fonte de dados para subsidiar o manejo dos recursos florestais.Técnicas de sensoriamento remoto têm propiciado informações de volume, biomassa e outros parâmetros biofísicos de povoamentos florestais. Nesse contexto, o principal objetivo deste trabalho é mapear, a partir de dados do sensor Thematic Mapper/ LANDSAT, o volume contido em povoamentos de coníferas, utilizando para tal a técnica de modelo de mistura espectral (SMA). Imagens-fração derivadas do modelo de mistura espectral mostram propriedades biofísicas mais facilmente que as bandas originais por representar melhor os aspectos físicos da cobertura do terreno. A área de estudo selecionada corresponde a região de El Alto Valle del Ebro (Espanha), com dimensão de 50km x 50km,cuja imagem de satélite é datada de 13/07/1996. No procedimento metodológico foram adotados três principais passos: 1) a aplicação do modelo de mistura espectral a partir das bandas originais TM 3, 4, 5 e 7 (as mais empregadas em estudos de vegetação) gerando imagens sintéticas;2) as componentes-fração "vegetação", "solo"e "sombra" dessas imagens sintéticas foram relacionadas com a variável de volume com casca (OBV), cujos dados foram extraídos do II Inventário Florestal Nacional da Espanha – NFI2-, a partir de técnicas de regressão e análise multivariada; 3) um mapa de volume foi obtido através de técnicas de interpolação, usando dados de modelo alométrico e de área basal. A principal conclusão desse trabalho relata a possibilidade de obtenção de um modelo matemático (R2 ajustado de 0,75) que permite estimar o volume florestal a partir de imagens satelitárias de média resolução espacial. A utilização do modelo desenvolvido com subsídio de informações derivadas de ortofotos digitais permitiu elaborar um mapa de volume estimado.

Palavras-chave: Inventário florestal; sensoriamento remoto; povoamento de coníferas; mapeamento de volume; mistura espectral

INTRODUCTION

The woody volume of a forest stand is such an important parameter that any extraction without this being known is simply not viable and the sustainable management of forests would be impossible. (STELLINGWERF e HUSSIN, 1997). The classical way to quantify forest stand volume was by using volume tables with one or more entries. However, in the last few decades, the stand volume has been quantified by regression models based on aerial photographs. At present various forestry agencies use remote sensed images, in addition to aerial photographs, to detect, identify, classify, evaluate and measure the different forest covers and the changes produced in them.

Traditionally, spectral vegetation indices (Normalized Difference Vegetation Index, NDVI, specially) have been used to infer biophysical vegetation properties. For instance, Gong et al. (1995) found that NDVI and Leaf Area Index (LAI) were positively correlated with coniferous forest. However, other studies found that NDVI was not the best indicator: Elundh et al. (2001) found a weak correlation between LAI and NDVI; and Huete et al. (1997) indicated that NDVI spectrally saturated over forested areas and was sensitive to canopy background reflectance change. The use of fraction images, derived from Spectral Mixture Analysis (SMA), can offer an alternative to applying a variety of spectral indices and correlations with measured leaf and crown-based attributes.

SMA procedure was used in this study to transform the original image and then regression analysis was used to relate the obtained fraction images with the Over Bark Volume OBV (m3/ha.) extracted from the data of the Second Spanish National Forest Inventory (NFI2). Fraction images from spectral unmixing show biophysics properties more easily than original bands because they represent physics aspects of ground covers. Thus, the main objective of this study was to evaluate the utility of SMA and to quantify the volume of a stand of *Pinus sylvestris* L. from Landsat Thematic Mapper (TM) images in Mediterranean areas.

STUDY AREA

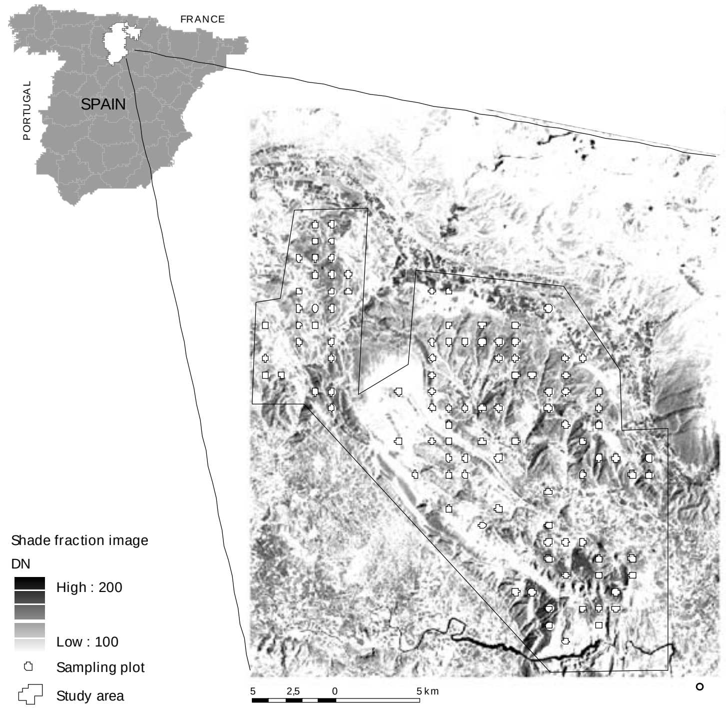
The study area was the Upper Ebro Valley Burgos and Álava (Spain), and the surface area studied was 952 km2. The climate in the Upper Ebro Valley corresponds to inland mid-mountain areas, and is characteristic of transition zones between the Atlantic and the Mediterranean with hot, dry summers and winters with abundant snowfall. The tree covered area constitutes more than 58% of the total forest area, highlighting Scots pine stands (*Pinus sylvestris* L.)

METHODOLOGICAL APPROACH

The satellite information used in this study came from a Landsat TM mini-scenes, (50x50 km), acquired on 13th July 1996. The relationships between forest stand parameters and Landsat TM spectral responses were showed in different scientific publications as Dengsheng et al. (2004), Mäkelä e Perkkarinen (2004), Santos et al. (1999), Magnusson e Fransson (2004).

The information on stand volume was taken from the Spanish NFI2 in the study area. The advantages of using the NFI2 plots instead of experimental ones are mainly: 1) the objectivity of the sampling of the forest stands; 2) the existence of a large quantity of data; 3) their homogeneity; and 4) the uniformity of their geographical distribution. Figure 1 shows the location of considered NFI2 plots.

Figure 1. Location of considered NFI2 plots



First at all, it was necessary to correct the images radiometrically and geometrically. Geometric correction needed Ground Points (GP) to be located on 1: 50 000 maps. A sampling linear transformation and the nearest neighbour were also used to obtain a geometrically corrected image with error < 1.5 pixels.

The conversion to reflectance values was considered unnecessary since an important behaviour of SMA is its invariance under linear transformations. Linear SMA assumes that pixel values are linear combinations of reflectances from a limited set of constituent elements, called endmembers. Each field on the scene contributes with a quantity of signal received on the sensor characteristic of the type of field cover and proportional to the area occupied within the pixel. In addition, the sum of these basic cover proportions must be the unit for each pixel. In this way the linear model is defined for each pixel of the image by the following equation:

$$x = Mf + e$$

where,

x: n-dimension digital-number vector;
M: n x c endmember spectra matrix;
n:is the number of bands used;
c:the number of endmembers;
f: c-dimension fraction vector;
e: n-dimension error vector, representing residual error.

On resolving the previously posed system of equations, a fraction image is obtained for each endmember defined which represents an estimate of the proportion of pixel occupied by that endmember. An image of error made in the transformation is also obtained.

The NFI2 data of interest for the work database were extracted using the BASIFOR program. This program allows the plot data complying with certain requisites established by the user to be extracted easily. (DEL RIO et al., 2001). The database was prepared for locating the relations between the satellite images and the forest stand parameters.

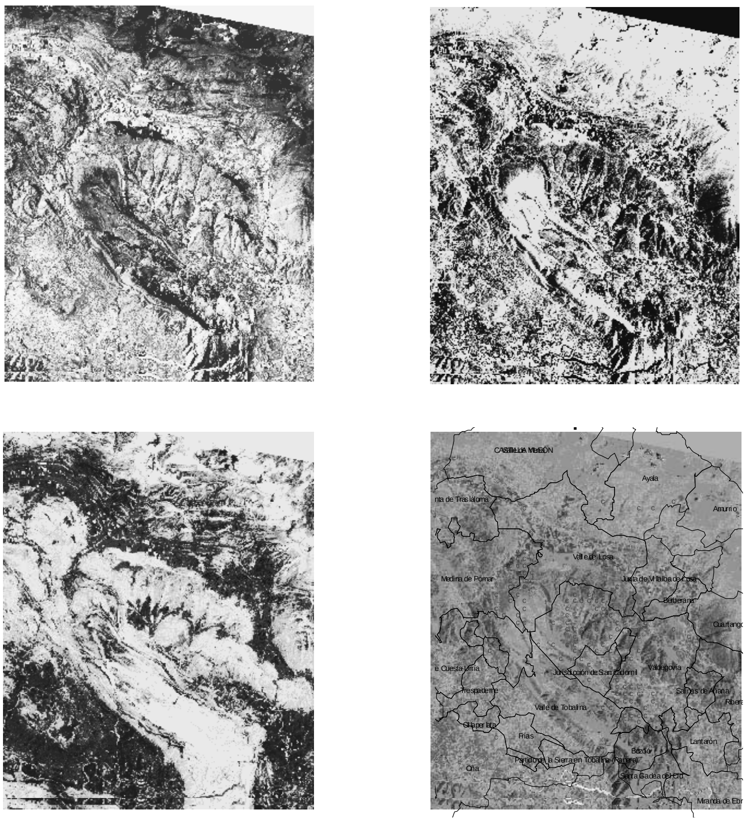
The analysis of multiple regression tries to establish an equation to define the existing relation between the dependent variable, ‘y’, (Over Bark Volume, OBV), and a set of independent variables, ‘x1’, ‘x2’, ..., ‘xp’, (fraction images). After defining the equations of regression, the R2 coefficient obtained was revised and an analysis of the residuals was carried out. In order to define the equation of regression only half of the available plots were used, reserving the other half for evaluating the equation obtained. Once the estimation model had been validated, it was applied to produce an estimated volume map.

RESULTS AND DISCUSSION

Before applying SMA, it was necessary to identify the endmember signatures, which had been extracted directly from the image (called image endmembers). Starting from the scatter plot it was possible to select the radiance intervals of the vegetation, shade and soil endmembers, identifying the purest pixels. (QUINTANO et al., 2005; QUINTANO et al., *in press*).

Once the unmixing was correctly performed and the fraction images were obtained (see Figure 2) a mean filter was applied (to minimize the possible registration error between the plots considered and the satellite image) and its digital value in the considered plots was extracted. A total of 107 plots in the July image were considered valid (53 for obtaining the estimate and 54 for verifying it).

Figure 2. Fraction images (13th July 1996)



On analyzing the relationship between the fraction images and the OBV variable was observed a low correlation index (R2 = 0.34) between the shade image and OBV, but of great significance. The problem of the low correlation between satellite data and forest parameters had already been recorded by other researchers. (AHERN et al., 1991; HYPPÄ et al., 2000). Trying to solve this problem, the data were first grouped depending on the OBV variable, as suggested by Ardö (1992), but on considering the rest of the plots not previously used, the estimation was seen to be not valid. Finally, an attempt was made to define the relation between these variables considering the different levels of volume existing, analyzing the behavior of each volume group defined independently. For a faster and clearer visualization these groups were defined by percentiles of 25%, 50%, 75% and 99% (low volume, medium volume, high volume, and very high volume, respectively) instead of by cluster analysis (Table 1 shows the considered volume groups).

Table 1. Volume groups

Volume Group	Average volume (m^3/ha)	Plots considered
Low volume	55.3	13
Médium volume	93.7	13
High volume	130.6	13
Very high volume	221.9	14

After this stage the regression between the stand volume and the fraction images was done group by group, obtaining a R2 equal to 0.913 and an adjusted R2 equal to 90.51 (p-value < 0.001).

In order to validate the analysis carried out, the 54 plots not used so far were employed. On this occasion, the Pearson coefficient of correlation between the observed and estimated volumes was 0.89 with a high level of significance (p-value < 0.0001). Figure 3 shows the results on applying the expression obtained in the verification plots. The equation of regression finally obtained was:

$$\begin{aligned} OBV = & -4.12 + 0.44 * shade \\ & + 33.14 * (GROUP\_OBV = \text{'medium volume group'}) \\ & + 70.06 * (GROUP\_OBV = \text{'high volume group'}) \\ & + 154.96 * (GROUP\_OBV = \text{'very high volume group'}) \end{aligned}$$

where,

GROUP_OBV = x is a logical variable which takes the value ‘1’ when the value of considered OBV belongs to group ‘x’, and value ‘0’ when it does not belong to that group.

Considering these results, it was possible to remark that: (1) there were good estimations when the volume not exceeded 200 m3/ha (very high volume); and (2) the worst estimations were observed when the volume belonged to the “very high” volume group. These affirmations agree with the results obtained by researchers as Ardö (1992).

Figure 3. Observed vs. estimated volume

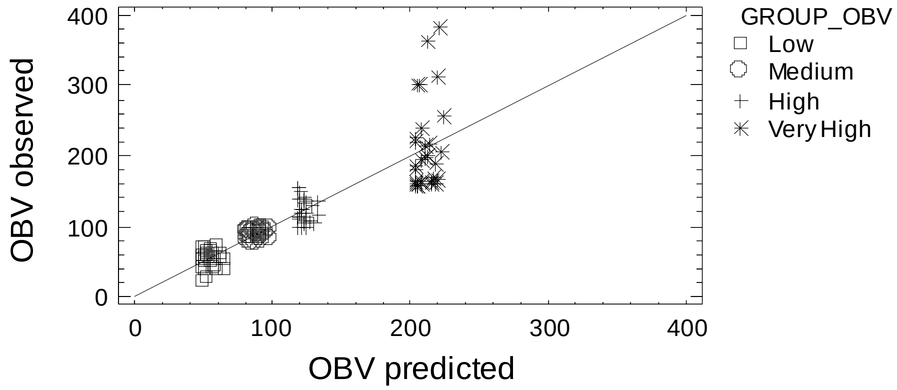
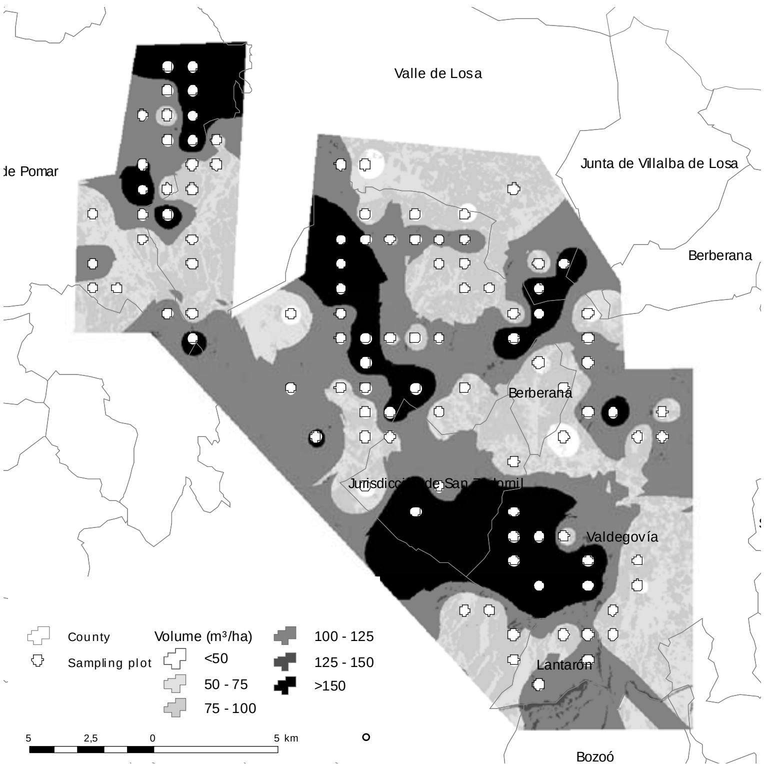


Figure 4. Estimated volume map



However, in spite of the good results obtained, this expression has practical limits as it does not allow the volume of a specific forest stand to be estimated unless certain knowledge of it is available. To minimize this problem, three steps were carried out:

1) the mass was stratified (considering the four volume groups before defined) by identification of different development levels on digital orthophotographs; 2) the model was applied to the shade fraction image to obtain the estimated volume, considering the volume groups defined in step 1; and 3) the estimated volume image was reclassified considering six volume classes with 25m3/ha intervals (Figure 4) (these classes are the common classes used by the Spanish Forestry System.

CONCLUSIONS

Bearing in mind the results obtained, the main conclusion of this study was to validate the utility of using SMA and regression techniques for quantifying the volume of a stand of *Pinus sylvestris* L. from Landsat TM images working in Mediterranean environments. To improve the way of obtaining the volume map, we are working in automating the digital orthophotographs stratification process by means of object oriented classification. The digital map produced can be integrated as a new source of data in the Information System of the regional forestry administrative authority.

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