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A Practical Example of Forest Mapping and Timber Volume Estimation Using Landsat-5 TM Imagery*

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ABSTRACT

The objective of this project was to obtain basic forest information of Uruguay. This report describes a methodology which used Landsat TM data as a first segment of a two-stage sampling plan designed to produce typical forest inventory information for plantations (pine and eucalypt) and to map forest areas. From all the result obtained, the project could conclude that Landsat-5 TM imagery, at a scale of 1:100,000, served well as the primary source of data for forest area mapping and timber inventory over a nation-wide level.

INTRODUCTION

The main objective of this project was to obtain basic forest information for development, promotion and utilization of alternative sources of energy based on the use of the country's forest resources, and to evaluate the forest Landsat Thematic Mapper (TM) data as an aid to forest plantations management in Uruguay. The project attended to the need of evaluating Uruguay's forest potentials in order to develop a reforestation programme for the use of wood as an alternative source of energy. To accomplish this evaluation, it was necessary first to establish the spatial distribution of the forest cover and evaluate the existing volume of stand timber. Considering that the Landsat TM imagery covers the same area every 16 days and has spatial resolution of 30 meters, these data, added to the ground information surveys, provide a cost-effective means of evaluating current timber resources and planting areas, at a national level. The specific objectives of the project were: (1) to obtain maps of Uruguay forested areas at scales of 1:100,000, including natural stand with 50% canopy; (2) to obtain information on

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forest plantations for those maps; (3) to generate a map of the forested areas of Uruguay at a scale of 1:1,000,000; (4) to compute the stand timber volume in plantations areas. The area under study in this project corresponds to the Uruguayan territory, which is composed of 19 states called "Departamentos" and represents 176,027 square kilometers. Since the available of recent aerial photographs do not cover all the country, it was necessary to divide the territory in two zones: Zone I and Zone II. Recent aerial photographs were available for Zone II only.

METHODS AND MATERIALS

Visual Image Interpretation

The territory of Uruguay is covered by 44 quadrants of Landsat-5 imagery. The material used for interpretation and map compilation were black and white paper print images from Landsat TM, band 3 (0.63 to 0.69 μm), band 4 (0.76 to 0.90 μm) and some band 5 (1.55 to 1.75 μm) at 1:100,000 scale and band 3 at 1:1,000,000 scale. The methodology used was based on the visual interpretation of unenhanced Landsat TM imagery. The image analysis was conducted in two parts. The first part was conducted previously to the ground checking, and the second analysis was conducted after the field work, when the interpreters were more familiar with both ground features and their correspondence in the imagery. Based on spectral and spatial image attributes the interpretation was made by using a visual methodology. Taking into account the image spatial attribute it was analyzed the pattern and size of the topographical site occupied by the artificial (pine and eucalypt) and natural forest. Relating to the image spectral attribute it was analyzed the texture and tonality.

Thematic Map Compilation and Area Measurement

The interpretation of a Landsat image was drawn with a 5 km grid at 1:100,000 scale. The base map sheet was also used to control the organization and the localization of the information extracted from the images. The scale variation of the images and errors on the maps produced discrepancies between forest boundaries and map features. To minimize this kind of error, in the order of one kilometer on the ground at most, a procedure was adopted to distribute it over a whole scene. It consisted of working one by one each adjacent cell (5 km grid) of the base map and performing small adjustments between the interpretation overlay and the base map. To measure the forest areas it was used the overlay containing the interpreted forest classes. The area of plantations was estimated by superimposing a 0.4 mm grid overlay, and for estimating natural forest a 1 mm grid was used. Area acreages by class of Primary Sampling Units (PSU´s) were then measured and listed. For Zone II, a Secondary Sampling Unit (SSU) as being 1/625 of one PSU was defined. The area counting inside each SSU was done with a 1 mm grid overlay but superimposed on a mosaic of aerial photos at a scale of 1:20,000. Each photomosaic has 25 x 25 cm to cover a PSU, and each 1 x 1 cm corresponds to one SSU (200 x 200 m area on the ground).

Sampling Design

The methodology and procedure for timber volume estimate in multistage inventory with variable probability has been used in Brazil (Lee, et al., 1983, 1984 and Hernandez Filho, et al., 1985). With this experience, one established a two-stage sampling design with probability proportional to size (PPS) and simple random (equal probability) sampling. These procedure were used to estimate the plantation stand timber volume in the two zones.

Sampling Scheme. For Zone I, the method consisted of a two-stage sampling design using PSU's selected with PPS. In the second stage, each SSU was chosen on a simple random basis. The unbiased estimator (Cochran, 1977, P. 306-308) of the total timber volume (V_t) of each class can be expressed as:

$$V_t = \frac{1}{m} \sum_{i=1}^{m} \frac{N_i}{P_i n_i} \sum_{j=1}^{n_i} V_{ij}, \qquad P_i = x_i \Big/ \sum_{i=1}^{M} x_i,$$

where: P_i is the conditional probability of drawing the ith PSU, V_{ij} is the field measured value of timber volume in the jth SSU of the ith PSU, x_i is the forest area of a class in the ith PSU, N_i is the number of SSU's in the ith PSU, m is the number of PSU's selected in the class, M is the number of PSU's in the zone per class and n_i is the number of SSU selected in the ith PSU. The estimator for the variance is:

$$\text{Var } V_t = \frac{1}{m(m-1)} \sum_{i=1}^{m} \left(\frac{V_i}{P_i} - V_t\right)^2.$$

where: V_i is the estimated total timber volume in the ith PSU.

For Zone II, the variable probability sampling design was used where sample units of two stages were all selected based on PPS. The size was the acreage of plantations estimated within the PSU and SSU units. A generalized model for a two stage estimator based on Langley (1975) is:

$$V_t = \frac{1}{m} \sum_{i=1}^{m} \frac{1}{P_i n_i} \sum_{j=1}^{n_i} \frac{V_{ij}}{P_{ij}}, \qquad P_{ij} = x_{ij} \Big/ \sum_{j=1}^{N_i} x_{ij},$$

where: P_{ij} is the conditional probability of drawing the jth SSU in the ith PSU and x_{ij} is the forest acreage of the jth SSU in the ith PSU. The unbiased estimate of sample variance can be obtained from the estimate of the first stage, that is:

$$\text{Var } V_t = \frac{1}{m(m-1)} \left(\sum_{i=1}^{m} \frac{V_i^2}{P_i^2} - mV_t^2 \right).$$

This estimator of variance, based on a simple stage estimate, may also be used to determine the unbiased estimate of sample variance for a two-stage sample estimate (Langley, 1975). The precision of variable probability sampling is dependent on the relationship between the predicted values, which determine the sampling probability, and those determined by precise measurement (in this project it was the acreage of forest land areas). The premise here is that the greater the forest area within prescribed sample units, the greater the timber volume.

Sample Size and Allocation. The sample size is calculated by:

$$m = t^2 \cdot CV^2/E^2,$$

where: m is the sample size in the first stage, t is the normal deviation (two-sided) for a given confidence level, CV is the coefficient of variation of estimator and E is the allowable error in percent. The basal area per hectare of forest land (per class), estimated from a selected sample in the presampling field work, provides an approximation of the variation in forest land over the area being sampled and can be used to estimate the size of the sample in the first stage. As to sample allocation, the selection probabilities used in this project were equal probability and PPS. This procedure allows giving to the large units higher selection probabilities, since they represent larger portions of the population. This was the rationale for PPS selection which adapted for the project. Both methods were performed with replacement.

Field Volumetric Measurement

In the second stage, the field work was carried out to determine the stand timber volume for the selected sample units (SSU´s). The mean stand volume, mean basal area and mean stand height from the sampled plots were estimated using the Strand´s Line Sampling method with the Relaskop of Bitterlich (Bitterlich, 1984, P. 43-46). Using the field work data, the SSU´s, the PSU´s and the total stand timber volumes were then calculated using the equations defined in before section.

Accuracy Assessment

The errors in the interpretation of the Landsat imagery affect: (1) the placement of the boundaries, and (2) the identification of the classes delimited on them. This leads to errors of misclassification and misplacement and, therefore, to errors of area estimation for the classes concerned. To calculate the accuracy of the forest cover mapping, a sample from the total population of the classified units (SSU´s) was selected and a field check for this chosen sample was carried out.

RESULTS AND DISCUSSION

Visual Interpretation

Table 1 shows a photointerpretation key for the three main classes using Landsat TM imagery. But tone and texture of these classes vary somewhat according to the age, site, density, crown size and type of timber growth. This experience has permitted to observe that:

1. On image prints, the pine plantation appears in dark grey (low reflectance) on band 3 (chlorophyll absorption band), but it appears lighter (high reflectance) on band 4 (reflecting IR radiation band) than on band 3.

2. Shape and size were a very important key to distinguish plantations and natural forest. In flat pastureland, the isolated plantation areas can easily be determined at the minimum area of one hectare. The shape of plantation areas always shows regular forms.

3. Shadow is useful for identifying plantations, specially for isolated small areas in band 4. These areas are always accompanied by dark grey shadows.

4. Fairly homogeneous plantation areas of more then 4 hectares can be identified on image of band 3, in part due to their linear boundaries. Separation of pine and eucalypt is more clear on band 4.

Table 1. Photointerpretation key of analysis

	Tone		Texture	
Class	Band 3	Band 4	Band 3	Band 4
Pine	DG (dark grey)	G (grey) to DG	F (fine)	MC (more coarse)
Eucalypt	G to DG	Light Grey	F	F
Natural Forest	G to DG	G	MC	MC

Interpretation and Mapping Accuracy

The confusion matrix was generated through visual interpretation results. They display the corresponding accuracies which were evaluated when compared with ground data from a field sample check. Table 2 shows the overall interpretation and mapping accuracies which were 90.6% and 83.3% respectively. Thus, the interpretation accuracies for pine and eucalypt are 82.4% and 95.5% respectively, and the mapping accuracies for pine and eucalypt are 81.9% and 81.4% respectively. The area of eucalypt plantations had been overestimated by 15.3% and that of pine plantations had been underestimated by 17.6%. These are somewhat low accuracies in comparison with the commission error of pine (0.7%) and the omission error of eucalypt (4.5%) plantations. The confidence intervals and the sampling errors of interpretation and thematic mapping accuracies were calculated and each of them at 95% confidence level. all accuracy requirements for each class of interpretation and thematic mapping were met (sampling error around 5%) except those for natural forest (Table 3).

Forest Area

Uruguay has a total area of 176,027 square kilometers, and according to this project we conclude that the total forest area is about 3% of the total land area in Uruguay. The plantation forest (pine and eucalypt) is about 23.7% of the total forested area. Natural forests are concentrated basically along rivers and drainage. In the pastoral region, part of plantation forest types were not planted for the purpose of timber woods, but for sheltering livestock in stockfarms or to serve as windbreak belts. This resulted in small and sparse forest plantations with sizes from 0.25 to 20 hectares.

Volumetric Results

The statistical results of the total stand timer volume for Zone I and II are presented in Table 4. The form factor used for pine plantations was 0.45 and for eucalypt plantations was 0.50. The stand timber volume per "departamento" in cubic meter was generated by the data of forest acreage and the mean stand timber volume. The total volume timber of Pinus spp. and Eucalyptus spp. plantations in the whole country were estimated as 3,539,418.15 cubic meters and 24,231,118.83 cubic meters respectively.

Table 2. Confusion matrix for accuracy analysis

Image interpretation	Field check			
	Pine	Eucalypt	N. forest	Others
Pine	267	2	0	0
Eucalypt	49	276	0	1
Natural forest	0	0	69	6
Others	8	11	7	197
Total	324	289	76	204
Commission error (%)	0.7	15.3	8.0	11.7
Omission error (%)	17.6	4.5	9.2	3.4
Interpretation accuracy (%)	82.4	95.5	90.8	96.6
Mapping accuracy (%)	81.9	81.4	84.2	85.7
Overall interpretation accuracy (%)				90.6
Overall thematic mapping accuracy (%)				83.3

Table 3. Accuracy assessment

Class	Interpretation		Thematic mapping	
	Sampling Error(%)	% Correct & Conf.Interval	Sampling Error(%)	% Correct & Conf.Interval
Pine	5.04	82.4±4.2	5.13	81.9±4.2
Eucalypt	2.50	95.5±2.4	5.52	81.4±4.5
Natural Forest	7.20	90.8±6.5	9.80	84.2±8.3

Table 4. The results of the estimated timber volume

Class	Pine	Eucalypt
Zone I		
Total timber volume (m^3)	1,710,608.20	15,429,409.34
Standard error (m^3)	140,002.10	1,933,835.94
Relative standard error (%)	8.18	12.53
Upper 95% confidence limit (m^3)	1,985,012.32	19,219,727.78
Lower 95% confidence limit (m^3)	1,436,203.88	11,639,090.90
Relative conf. interval (%)	±16.03	±24.56
Mean & conf. interval (m^3/ha)	145.34±23.30	243.64±59.84
Zone II		
Total timber volume (m^3)	1,828,805.95	8,801,709.49
Standard error (m^3)	199,320.85	855,837.62
Relative standard error (%)	10.90	9.72
Upper 95% confidence limit (m^3)	2,176,275.98	10,537,951.18
Lower 95% confidence limit (m^3)	1,438,140.98	7,065,467.71
Relative conf. interval (%)	±21.36	±19.06
Mean & conf. interval (m^3/ha)	225.38±48.14	217.57±41.47

CONCLUSIONS

Several conclusions were reached during this project and may be summarized as following:

1. It was possible to establish that the forest area mapping and inventory at a national level in Uruguay can be done satisfactorily using Landsat-5 TM images.

2. The characteristics of forest classes may be recognized using combinations of tone, texture, shape and size in two spectral bands (3 and 4) of Landsat TM imagery.

3. Shadowing is an useful tool in the identification of forest plantations, specially for isolated small areas in TM band 4. These areas are always accompanied by dark grey tones.

4. Visual interpretation is a very simple and efficient methodology for mapping forest land using Landsat TM imagery at a scale of 1:100,000 in paper prints. This is indicated by the figures obtained for the overall interpretation and mapping accuracies of 90.6% and 83.3% respectively.

5. At 1:100,000 scale, the Landsat TM imagery shows differences in forest stand structure, usually in a conspicuous manner. Nevertheless species identification may sometimes be difficult, such as differences among species from Eucalyptus, Populus and Salix spp.

6. Generally the greater the forest area within a sample unit, the greater the timber volume. However, age cutting and the difference in growth rates lead to variations in volume not necessarily associated with the area size.

7. The Strand´s Line Sampling method was useful only when a sufficiently large number of a sample size was used. When the trees not uniformly distributed in a SSU, the method employed could not be a good estimator of basal area, height and volume of a single SSU just a few measurement.

8. In future works it is suggested an attempt to establish a regression model between data obtained from satellite, aerial photographs and field work, for different forest classes, in order to analyze and improve the final results.

9. Accordingly to the objectives of this inventory, the results and the accuracy of the obtained information can be considered satisfactory. Nevertheless, for a more comprehensive analysis of the forest resources, it is suggested a plantation stratification by groups of species, sites and ages.

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