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FUNCATE
Fundação de Ciência, Aplicações e Tecnologia Espaciais

FINAL REPORT

for

UNIDO Contract Nº 85/125/MK

Project Nº DP/URU/013

ASSESSMENT OF FOREST RESOURCES IN URUGUAY

submitted to

The United Nations Industrial Development Organization (UNIDO)

submitted by

FUNCATE (Fundação de Ciência, Aplicações e Tecnologia Espaciais)
São José dos Campos, São Paulo, Brazil

July 1987

Dr. João Guilhermino, 429 - 11.° Andar - Tel. (0123) 22-4987 - Ed. Saint James - São José dos Campos - 12.245 - São Paulo - Brasil

SUMMARY

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 Uruguay's natural resources. Another objective of this project was to evaluate the Landsat Thematic Mapper (TM) data as an aid to forest resource management in Uruguay.

Additionally, training was provided to a team of eight Uruguayan specialists on interpretation of satellite data for forest mapping and forest measuring techniques.

The area under study in this project corresponds to the Uruguayan territory, with a total area of 176 027 square kilometers.

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 each of the two plantations (pine and eucalypt) and to map natural forest in Uruguay.

Thematic maps of the plantations (pine and eucalypt) on the scale of 1:100 000 (87 sheets) and natural forest on the scale of 1:1 000 000 (one sheet) were prepared. For that reason, techniques and procedures were used, which have been developed by specialists from the Institute for Space Research in Brazil. These techniques were based on enhanced and unenhanced Landsat images, aerial photointerpretation and field surveys over several distinct and limited areas which were extrapolated for the interpretation of the whole country.

From the results of this project we can conclude that the total forest area is only about 3% of the total land area in Uruguay. The plantation forest (pine and eucalypt) which has high productivity of woods, is about 23.6% of the total forested area.

The accuracy of forest cover map was assessed by comparing a sample of the results obtained from graound check. The interpretation accuracies and sampling errors (in percentage) of pine was 82.4 $\pm$ 4.15 and of eucalypt was 95.5 $\pm$ 2.39. The mapping accuracies and sampling errors (in percentage) of pine was 81.9 $\pm$ 4.20 and that of eucalypt was 81.4 $\pm$ 4.49, all at the 95% confidence level.

Visual interpretation is a very simple, timely and highly accurate approach for mapping forest land using Landsat-TM imagery at a scale of 1:100 000 in paper prints. The overall interpretation and mapping accuracies were 90,6% and 83.8%, respectively.

The total stand timber volume of pine and eucalypt plantation in the whole country was estimated as 3.539.448 cubic meters and 24.231.118 cubic meters, with an sampling errors from 16.03% percent to 24.56% respectively, all at the 95% confidence level.

From all the results obtained, one can conclude that Landsat TM imagery, on the scale of 1:100 000, worked well as the primary source of data for forest area mapping and timber inventory over a nation wide area.

LIST OF CONTENTS

CHAPTER 1 - INTRODUCTION

In response to a request of the Oriental Republic Government of Uruguay in November 1985, the Foundation for Space Science, Applications and Technology (Fundação de Ciência, Aplicações e Tecnologia Espaciais - FUNCATE) submitted a project proposal to the United Nations Industrial Development Organization (UNIDO) named "Assessment of Forest Resources in Uruguay".

The main objective of this 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. Another objective was to provide training to a team of eight Uruguayan technicians on orbital imagery interpretation for forest coverage informations.

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 to evaluate the existing volume of timber plantations. Considering that the TM Landsat imagery covers the same area every 16 days and has spatial resolution of 30 meters, these data, added to the ground informations surveys, provide a cost-effective mean of evaluating current timber resources and planting areas, at a national level.

The specific objetives of the project were:

1) to obtain maps of Uruguay forested areas on scales of 1:100 000, including natural stands with 50% canopy or a density greater than 200 trees/hectare;

2) to obtain information on forest plantations for those maps;

3) to generate a map of the forested areas of Uruguay on the scale of 1:1 000 000;

4) to compute the stand timber volume in plantations areas.

FUNCATE started to perform the Project PNUD - MIE - UNIDO/URU/83/013 in December, 1985. The work-task "Fuentes Alternativas de Energia" organized an inter-institutional team to work in the project as an Uruguayan counterpart.

The following Uruguayan institutions and technicians participated in the Project:

. Industry and Energy Ministry

- Agr. Forest Eng. Rosario Pou Ferrari
- Agr. Forest Eng. Gerardo Almeida Demarco
- Agr. Forest Eng. Gustavo Gamundi

. University of Uruguay - Agronomy Faculty

- Agr. Forest Eng. Arianna Sorrentino

. Fishing and Agriculture Ministry

- Agr. Forest Eng. Peter U. Baptista Peláez
- Forest Tech. Francisco de Castro e Silva

. Military Geographic Service

- Lieutenant Edilberto Viar

The following Brasilian institutions and technician participated in the project:

. Science and Technology Ministry - Institute for Space Research

- Eco. René Antonio Novaes

- Forest Eng. Armando Pacheco dos Santos
- Forest Eng. David Chung Liang Lee
- Forest Eng. Flavio Jorge Ponzoni
- Forest Eng. José Simeão de Medeiros
- Forest Eng. Pedro Hernandez Filho

. Foundation for Space Science, Applications and Technology - FUNCATE

- Agr. Eng. Kleber de Faria
- Agr. Eng. Marcos Covre
- Agr. Eng. Renato dos Santos
- Agr. Eng. Ricardo Leonardo Vianna Rodrigues
- Cart.Eng. Flavio Gewandsznajder
- Tech. João Ernani Silva
- Tech. Cassia Beatriz Sorbile Veiga

The project was based on methodology and procedures which have been developed by the Institute for Space Research (INPE) of Brazil.

CHAPTER 2 - STUDY AREA

The area under study in this project corresponds to the Uruguayan territory, which is composed of 19 states called "Departamentos": Artigas, Canelones, Cerro Largo, Colonia, Durazno, Flores, Florida, Lavalleja, Maldonado, Montevideo, Paysandú, Rio Negro, Rivera, Rocha, Salto, San José, Soriano, Tacuarembó and Treinta y tres (Figure 2.1).

Since the available and recent aerial photographs don't cover all the country, it was necessary to divide the territory in two Zones: Zone I and Zone II, the first one with 10 "Departamentos", and the second with 9 "Departamentos". Recent aerial photographs were available for Zone II only (Figure 2.1).

The territorial surface of Uruguay represents 176 027 Km^2, which corresponds to nearly 1% the South American area. The extension between its borders is 520 Km Southwards and 480 Km Westwards. The limits of the area are: Brazil (Northward and Eastward); the Atlantic Ocean (Southeastward); Rio de la Plata (Southward); and Argentine (Westward through Uruguay River).

The forested areas include natural and artificial forests (predominantly pine and eucalypt) and is only 3% of the total territory.

Natural forests are found usually along drainages and on the hills.

The artificial forest of pine is found, most times, along the coast region and its primary reason is to fix the sand dunes.

Typically, the eucalypt plantations are distribuided all over the territorial surface of the country and present variable extentions for sheltering livestock (shadow and protection) and/or windbreak belts. Nevertheless there are eucalypt plantations, in a few "Departamentos" and concretrated in some zones, especifically to produce wood.

ORIENTAL REPUBLIC OF URUGUAY

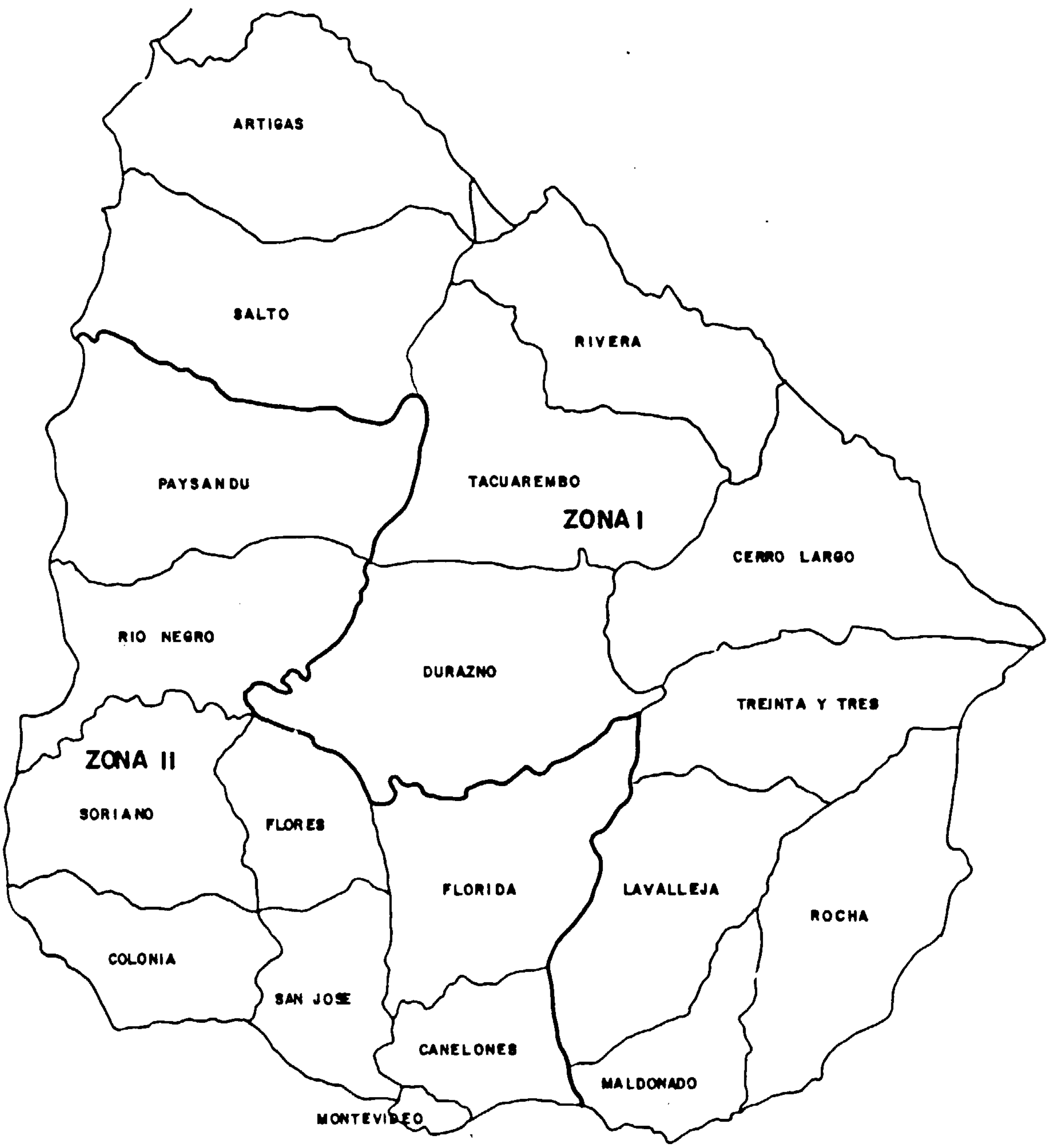

Figure 2.1 Study area : Limits of " Departamentos and Zone I and II "

The major planted Pinus spp. and Eucalyptus spp. in the country are: Pinus pinaster, P. elliottii, P. taeda, P. insigni, Eucalyptus tereticornis, E. camaldulensis, E. globulus and E. grandis.

CHAPTER 3 - MATERIAL

3.1 - SATELLITE IMAGERY

The territory of Uruguay is covered by 14 full frames or 44 image quadrants of Landsat (Figure 3.1). Most of them are cloud free, except for the path/row 224/84, which has no cloud free data from 2/5/85 to 12/7/85. More detailed informations are shown in Table 3.1.

The material used for interpretation and map compilation were black and white paper print images from the Landsat Thematic Mapper (TM), band 3 (0.63 to 0.69 μm), band 4 (0.76 to 0.90 μm) and band 5 (1.55 tp 1.75 μm) on the 1:100 000 scale and band 3 on the 1:1 000 000 scale. Images were acquired from INPE, Brazil by UNIDO.

3.2 - MATERIAL PROVIDED BY URUGUAY

The Uruguayan counterpart has provided all the necessary cartographic and bibliographic documents, as well as statistial data and all kind of important facilities to the project, as:

- 87 map sheets of the National Cartographic Series in cronaflex, on the scale of 1:100 000 which cover all Uruguay.

- Forestry Current Chart and Soils of Forestry Interest.

- All the available aerial photographs covering part of the uruguayan territory. Vertical black and white aerial photographs taken between 1980 and 1982 on the scale of 1:20 000 were used just for Zone II (Fig. 2.1). Those aerial photographs provided by the uruguayan counterpart were used as an aid material for ground surveying, to make the interpretation key and the area mensurations.
- The necessary bibliography describing the forest zones and other aspects of the uruguayan territory.

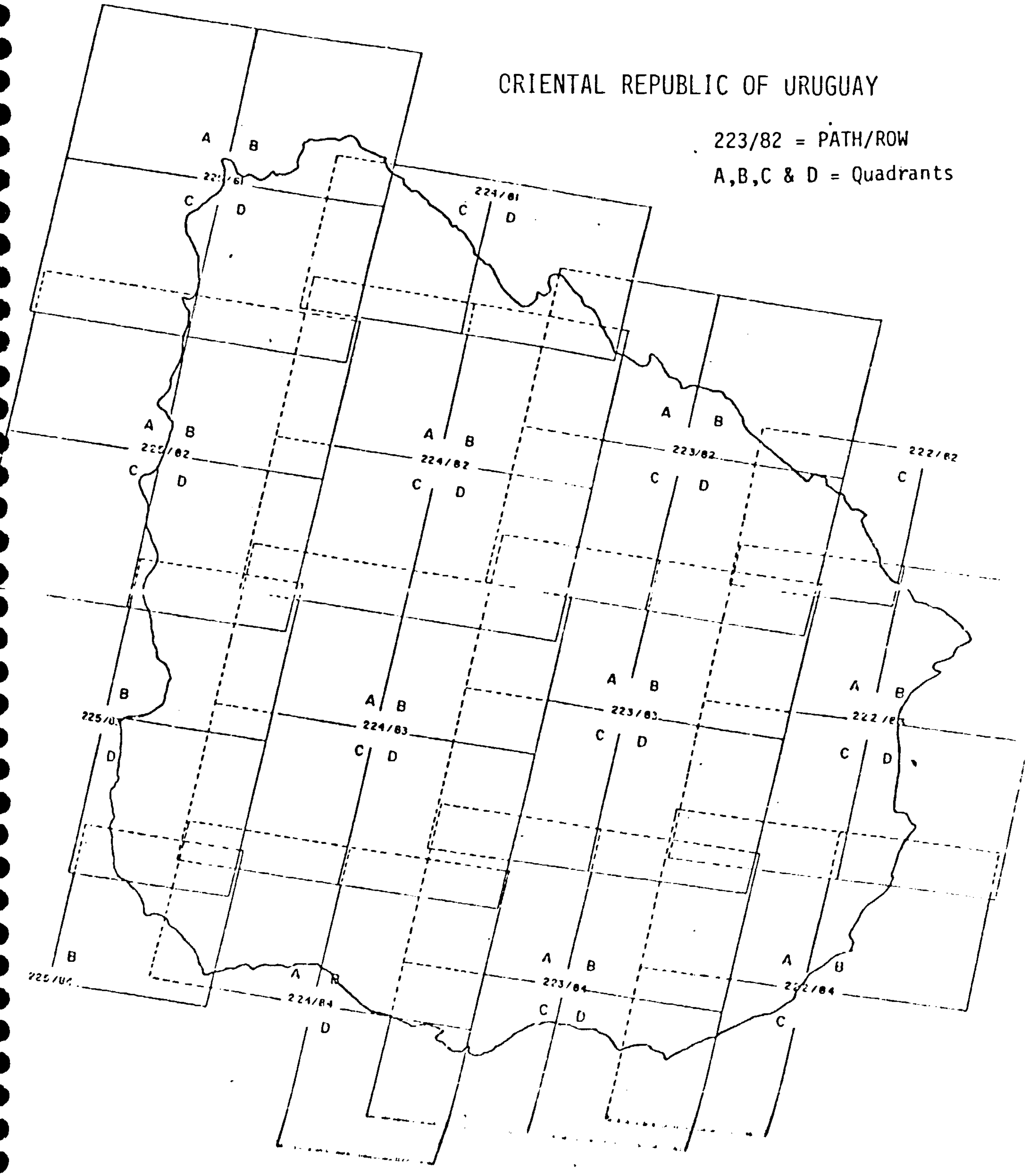

Figure 3.1 - Map of Uruguay showing the full frames and their quadrants of the Landsat-5 TM images.

TABLE 3.1

LANDSAT/TM IMAGES USED IN THIS PROJECT

PATH/ROW	ACQUISITION DATE	QUADRANT	SPECTRAL BAND
222/82	04/05/85	C	3 & 4
222/83	04/05/86	A,B,C & D	3 & 4
222/84	04/05/86	A,B & C	3,4 & 5
223/82	11/05/85	A,B,C & D	3 & 4
223/83	11/05/85	A,B,C & D	3,4 & 5
223/84	05/12/85	A & B	3,4 & 5
	07/02/86	A,B & D	3 & 4
	23/02/86	C	3 & 4
224/81	02/05/85	C & D	3 & 4
224/82	02/05/85	A,B,C & D	3 & 4
224/83	02/05/85	A,B,C & D	3 & 4
224/84	06/10/84	A,B & D	3 & 4
225/81	12/07/85	C & D	3 & 4
	10/06/85	A & B	3 & 4
225/82	12/07/85	A,B,C & D	3 & 4
225/83	12/07/85	B & D	3 & 4
225/84	12/07/85	B	3 & 4

3.3 - OTHER MATERIALS

. Relaskops of Bitterlich, short band model
. Calipers
. Tapes of 15,7 m of length (5 m)
. Compasses
. Range Finders
. Dot grid
. Milimeter scale
. Field data sheets
. Diameters tapes
. Hand magnifying glass
. Light camera tables

CHAPTER 4 - METHODOLOGY

The flow diagram in Figure 4.1 shows the sequence of the Project activities, and Table 4.1 the time required to perform each activity.

4.1 - VISUAL IMAGE INTERPRETATION

The methodology used was based on the visual interpretation of unenhanced Landsat-5 TM imagery, described by Hernandez Filho and Shimabokuro (1978, 1985).

The existing aerial photographs, forest maps and other auxiliary information on forest land were examined in conjunction with the imagery.

The image analysis was conducted in two stages. The first stage was conducted previously to the ground checking, and the second analysis (or reanalysis) was conducted after the field work, when the interpreters were more familiar with both ground features and their correspondence in the imagery.

During a training course for eight uruguayan techinicians (January, 1986) ground surveys were conducted to collect information on the tree height, basal area, density, minimum area that can be interpreted and species composition, which allowed the stablishment of preliminary interpretation keys.

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FLOW DIAGRAM OF THE PROJECT

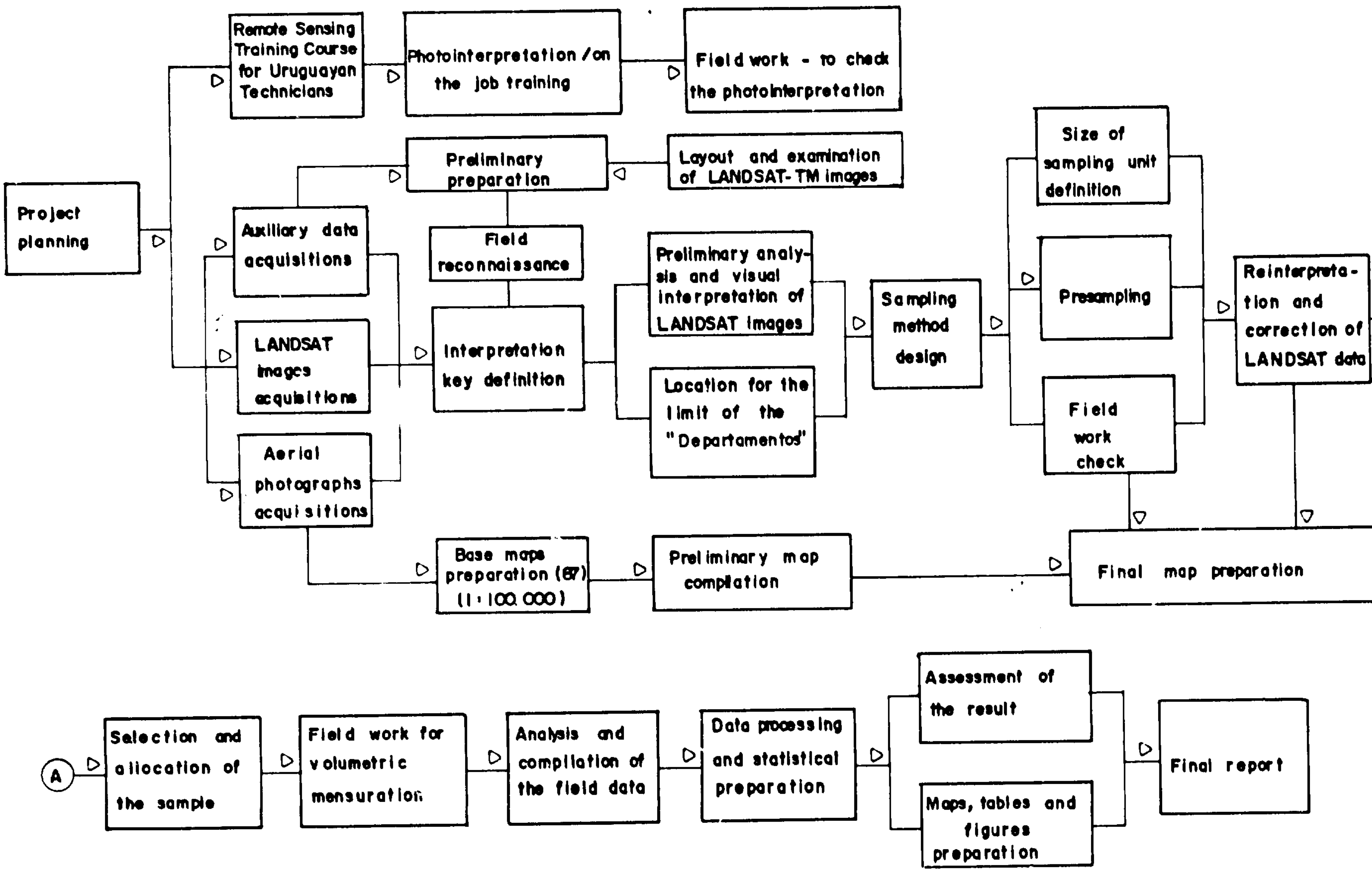

Figure 4.1

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FLOW DIAGRAM OF THE ACTIVITIES OF THE PROJECT

ACTIVITIES \ YEARS/MONTHS	1985 DEC	1986 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	1987 JAN
1. IMAGERY SELECTION AND ACQUISITION (BRAZIL).	16	18												
2. TRAINING COURSE PREPARATION (BRAZIL)		7 18												
3. TRAINING COURSE, FIELD CHECK AND AUXILIARY DATA ACQUISITION (BRAZIL)		19	2											
4. BASE MAP PREPARATION (BRAZIL)			3	29										
5. PRELIMINARY IMAGERY INTERPRETATION (BRAZIL)			10		5									
6. ON THE JOB TRAINING FOR URUGUAYAN SPECIALISTS (BRAZIL)			23	21										
7. INTERIM REPORT (BRAZIL)					7 12									
8. FIRST FIELD WORK (URUGUAY)					13 26									
9. IMAGERY REINTERPRETATION DATA INTEGRATION AND SAMPLE DEFINITION					28		28							
10. ON THE JOB TRAINING FOR URUGUAYAN TECHINICIANS (BRAZIL)							2 28							
11. PROGRESS REPORT (BRAZIL)							30	5						
12. SECOND FIELD WORK (URUGUAY)								6			4			
13. FIELD DATA ANALYSIS INTEGRATION AND EVALUATION (BRAZIL)										8	18			
14. MAPS, TABLES AND STATISTICAL FIGURES GENERATION (BRAZIL)										15		15		
15. DRAFT OF FINAL REPORT (BRAZIL)											20	22		
16. FINAL REPORT (BRAZIL - URUGUAY)												24		17

Table 4.1

In order to make this reconnaissance, 22 representative points were selected for field check, from four quadrantes of two Landsat images with the aid of some aerial photographs.

Based on spectral and spatial image attributes the interpretation was made by using a visual methodology. In general, a unique path for each image was analysed, althwith image dates varying from October, 1984 up to February 1986. For that reason it was not possible to evaluate the temporal aspects of the images during the visual interpretation phase.

Taking into account the image spatial attribute it was analysed the pattern and size of the topographical site occupied by the artificial and natural forest (pine and eucalypt). Relating to the image spectral attribute it was analysed the texture and tonality.

For the visual interpretation of the TM image it were used aerial photographs, as an aid in some areas of the country, and data on the artificial forest, provided by the uruguayan institutions.

On the cronaflex base map was superimposed a stable and transparent polyester paper and this set was superimposed on the Landsat images for interpreting the defined subject. The artificial and natural forests were painted with different colors and,to update the cronaflex base map,the roads, artificial lakes, etc, were drawn.

The interpretation of the forest land was accomplished first using the band 3, and after that the other Landsat bands (4 and/or 5) to confirm the class of forest.

The color of each class was coded (Table 4.2).

4.2 - AREA MEASUREMENT TECHNIQUES

To measure the forest areas it was used the overlay containing the interpreted forest classes.

The area of pine and eucalypt plantations was estimated by superimposing a 0.4mm grid overlay, and for estimating natural forest a 1mm grid overlay. Each base map (overlay) containing the classes to be measured included a 5 Km grid that was used as PSU (Primary Sampling Unit.). The transparent grid overlay (0.4mm or 1mm) can be moved and the measurements, for all succeeding 5 Km squares, can be made (Figure 4.2). Area acreages by class of PSU's were then measured and listed in Table 4.3.

For Zone II, a Secondary Sampling Unit (SSU) as being 1/625 of one PSU was defined. The counting inside each SSU was done with a 1 mm x 1mm grid overlay but superimposed on a mosaic of aerial photos on the scale 1:20 000. Each photomosaic has 25 cm x 25 cm to cover a PSU, and each 1 cm x 1 cm corresponds to one SSU (200 m x 200 m area on the ground) Figure 4.3.

TABLE 4.2

COVER CLASSES FOR LANDSAT TM INTERPRETATION

1. Forest Plantations

Minimum area 1 x 1 mm = 1 ha

(a) Pinus spp. plantations: printing red

(b) Eucalyptus spp. plantations: printing blue

2. Natural Forest - printing green

Mininum area 5 x 5 mm = 25 ha: greater than 50% canopy

Usualy along drainages and on the hills

3. Water Body

(a) Reservoirs and lakes

(b) Rivers

4. Others

(a) Agricultural land

(b) Urban land

(c) Roads and railroads

(d) Cities and villages

(e) Other spp. plantations

(f) Parks

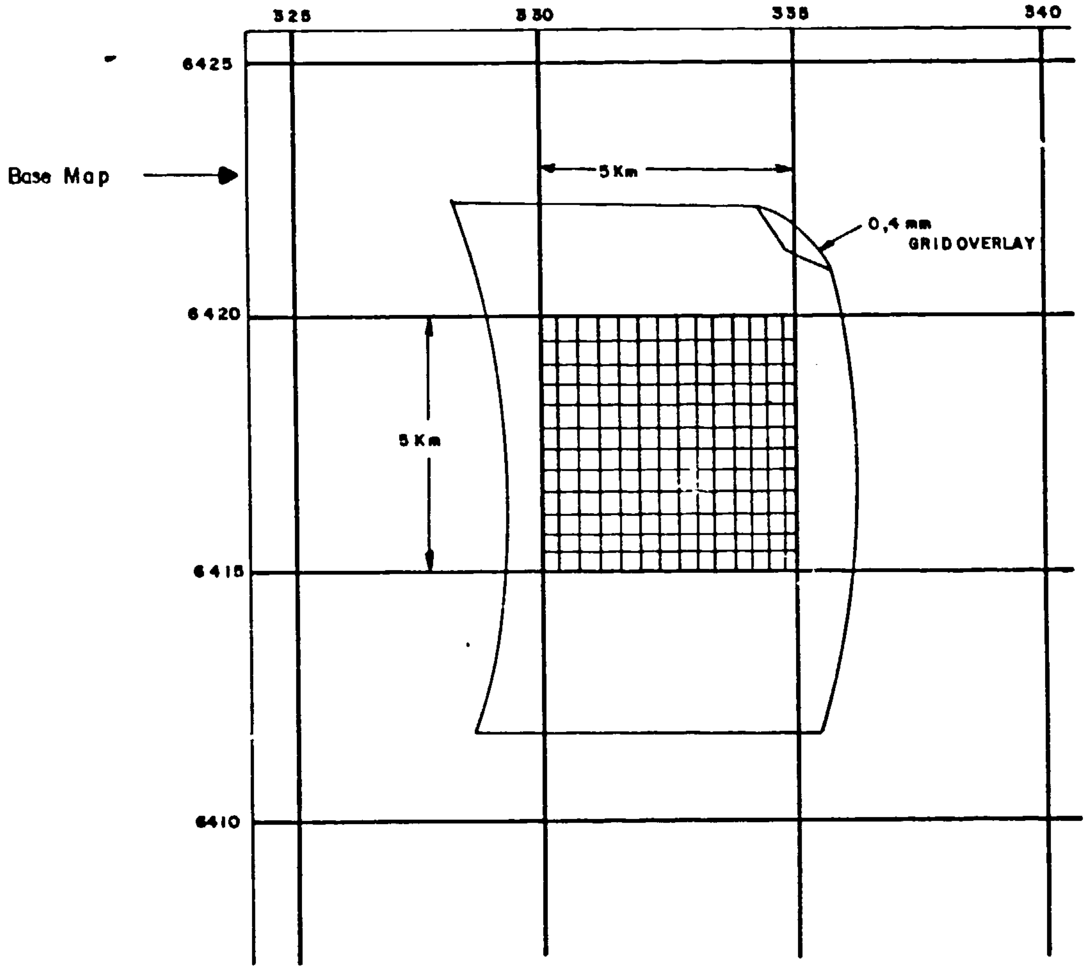

Figure 4.2 - Diagram showing the forest area measurement in a PSU of first stage.

TABLE 4.3

FORM TO AREA MEASUREMENTS

MAP:			AREA MEASUREMENTS OF CLASS IN HA.						OBS.
PSU		"DEPARTAMENTO"	PINE		EUCALIPYPT		NAT. FOREST.		
ROW	COLUMN		AREA / HA.	CUMULATIVE	AREA/ HA.	CUMULATIVE	AREA/ HA.	CUMULATIVE	

4.3 - THEMATIC MAP COMPILATION

The interpretation of a Landsat image was drawn on a stable and transparent paper "Terkron" superimposed to a cronaflex, containing a 5 Km grid on the 1:100 000 scale. The base map sheet was also used to control the organization of the localization extracted from the images.

The scale variation of the images and errors on the maps (rivers, roads, cost line, etc) 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 of the base map 5 km x 5 km grid and perfoming small adjustments between the interpretation overlay and the base map.

Since Landsat images are good approximation to geodetic maps, transferring details from them to existing maps poses no serious problems and can be done visually (FAO, 1980).

4.4 - ACCURACY ASSESSMENT

4.4.1 - SAMPLE SIZE FOR THE INTERPRETATION

The first concern in the task of assessing the accuracy of forest cover maps was the selection of a sample large enough to provide precision at a specified significance level, applicable to mapping and interpretation.

The sample unit to be bisited in the field was defined as the center point of each SSU (200 m x 200 m).

The sample size n (number of SSU) at the 95% confidence level was calculated by the following equation:

$$n = \frac{t^2 \, \tilde{p}(4-\tilde{p})}{E^2},$$

were $\tilde{p}$ is the expected accuracy (or assumed accuracy based on previous experience) and E is the allowable error (Snedecor and Cochran, 1967).

The value t = 2 is for a 95 percent confidence level. For example, a pine class map unit with an assumed accuracy of 70 percent and an allowable error E of 5 percent, at the 95 percent confidence level, would require a number of sample points equal to:

$$n = \frac{2^2 \, (70 \times 30)}{5^2} = 336.$$

4.4.2 - INTERPRETATION WORK

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.

The interpretation accuracy proposed by Kalensky (1976) are:

1. Overall interpretation accuracy (K%) is calculated as:

$$K\ (\%) = (\Sigma N_i / \Sigma T_i) \times 100,$$

where ΣN_i = total number of correctly classified points in all classes

ΣT_i = total number of points in all classes.

2. Mapping accuracy (M_i%) of classe i:

$$M_i(\%) = \frac{N_i}{N_i + E_i} \quad 100,$$

Where N_i = number of correctly classified points in Class i,

E_i = number of erroneous points in Class i,

(i.e. sum of omission and commission errors)

3. Overall mapping accuracy (M%):

$$M(\%) = \frac{\Sigma P_i \; M_i}{\Sigma \; P_i} \; 100,$$

where P_i = interpretation accuracy of Class i, $P_i = \frac{T_i}{\Sigma T_i}$,

T_i = correct number of point in Class i,

ΣT_i = total number of point in Class i,

A sample computation for each error type is illustrated below:

Error of omission (pine) = (49 + 8)/324 = 17.6%,

Error of commission (pine) = 2/269 = 0.7%,

Interpretation accuracy (pine) = 267/324 = 82.4%

Mapping accuracy (pine) = 267/(267 + 2 + 57) = 81.9%

Overall interpretation accuracy = (267 + 276 + 69 + 197)/893 = 90.6%,

$$\text{Overal mapping accuracy} = \frac{82.4 x 81.9 + 95.5 x 81.4 + 90.8 x 84.2 + 90.6 x 85.7}{82.4 + 95.5 + 90.8 + 90.6}$$

$$= 83{,}3\%.$$

An estimate of the variance of P_i is (FAO, 1973):

$$\text{Var}\;(P_i) = \frac{P_i\;(1 - P_i)}{n - 1},$$

where n = sample size

E.g.: the estimated variance of interpretation accuracy of pine is:

$$\text{Var P (pine)} = \frac{0.824\;(1-0.824)}{324-1},$$

which has a standard error:

$$Sp = \frac{0.824\;(1-824)}{324-1} = 2.12\%$$

The confidence interval (95%) is:

P ± 1.960 x Sp = 82.4% ± 1.96 x 2.12%

82.4% ± 4.15%.

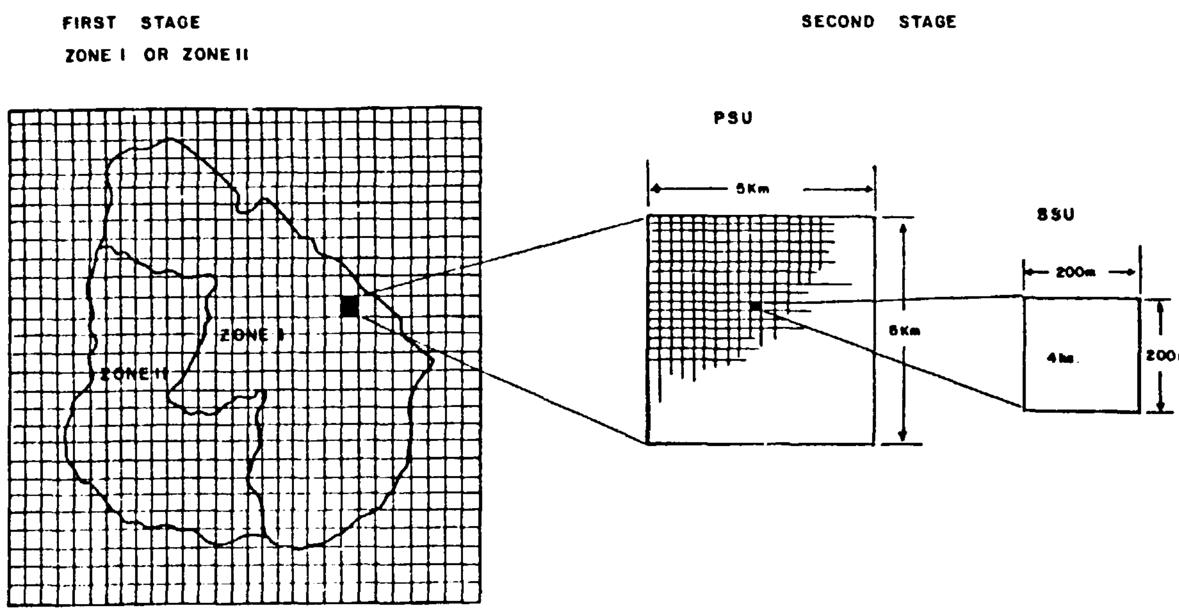
FIRST STAGE
ZONE I OR ZONE II
ZONE I
ZONE II
SECOND STAGE
PSU
5Km
5Km
SSU
200m
4ha.
200m

TABLE 4.4

FORM FOR SECOND SAMPLE SELECTION

ZONE:				CLASS:										
MAP:				NO										
PSU:				LINE		COLUMN								
SSU		AREA		TIMES BEING SELECTED										OBS.
LINE	COL.	POINT	CUMULATIVE TOTAL	1	2	3	4	5	6	7	8	9	10	

PSU grid on photomosaic
(1 x 1 cm)

SSU grid
(1 x 1 mm)

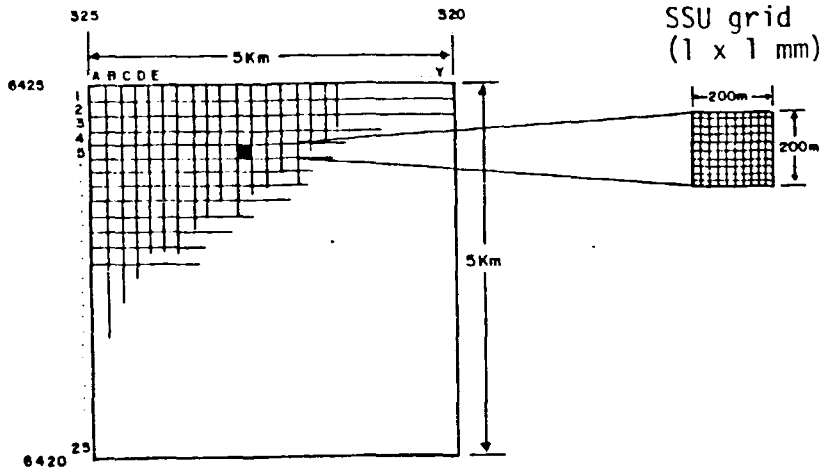

Figure 4.3 - Diagram of the Sampling design showing the scheme of subsamples at the second stage of zone II.

4.5 - SAMPLING DESIGN

The metodology and procedure for timber volume estimate in multistage inventory with variable probability has been used in Brazil (Lee, 1984; Hernandez, 1985). With this experience, one established a two-stage sampling design with probability porporcional to size (PPS) and simple randon (equal probability) sampling (SRS), all with replacement. These procedure were used to estimate the plantation stand timber volume in the two zones (Figure 4.4).

TABLE 4.5

SAMPLE SIZE OF MAPPING AND INTERPRETATION ACCURACY EVALUATION

Class	$\tilde{p}$	Sample size calculated with E = 5%	Number of points checked in the field	Number of points planned to be checked in the field
Pine	70	336	382	324
Eucalypt	80	256	283	289
Nature Forest	95	76	96	76
Others	85	204	224	204
Total		872	985	893

4.5.1 - SAMPLING SCHEME

1. Two-stage PPS-SRS Sampling Scheme:

For Zone I, without aerial photographs, the method consisted of a two-stage sampling design using primary sampling units (PSU's) selected with probability proporcional to their size (PPS) and with replacement. In a second stage, each secondary sampling unit (SSU) was chosen on a simple random basis. The unbiased estimator (Cochran, 1977) of the total timber volume of each class can be expressed as:

$$\hat{V}_t = \frac{M}{m} \sum_{i=1}^{m} \frac{V_i}{P_i} \quad \text{for the first stage,}$$

$$V_i = \frac{N_i}{n_i} \sum_{j=1}^{n_i} V_{ij} \quad \text{for the second stage}$$

where:

$\hat{V}_t$ is the estimated total timber volume per class in Zone I or Zone II,

V_i is the estimated total timber volume in the ith PSU,

P_i is the conditional probability of drawing the ith PSU, $P_i = \frac{X_i}{\sum_{i=1}^{M} X_i}$,

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,

n_i is the number of SSU selected in the ith PSU.

4.5.1 - SAMPLING SCHEME

1. Two-stage PPS-SRS Sampling Scheme:

For Zone I, without aerial photographs, the method consisted of a two-stage sampling design using primary sampling units (PSU's) selected with probability proporcional to their size (PPS) and with replacement. In a second stage, each secondary sampling unit (SSU) was chosen on a simple random basis. The unbiased estimator (Cochran, 1977) of the total timber volume of each class can be expressed as:

$$\hat{V}_t = \frac{M}{m} \sum_{i=1}^{m} \frac{V_i}{P_i} \quad \text{for the first stage,}$$

$$V_i = \frac{N_i}{n_i} \sum_{j=1}^{n_i} V_{ij} \quad \text{for the second stage}$$

where:

$\hat{V}_t$ is the estimated total timber volume per class in Zone I or Zone II,

V_i is the estimated total timber volume in the ith PSU,

P_i is the conditional probability of drawing the ith PSU, $P_i = \dfrac{X_i}{\sum_{i=1}^{M} X_i}$,

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,

n_i is the number of SSU selected in the ith PSU.

The estimator for the variance is:

$$\text{Var } \hat{V}_t = \frac{M}{m\,(m-1)} \sum_{i=1}^{m} \left(\frac{V_i}{P_i} - \hat{V}_t \right)^2 .$$

2. <u>Two-stage PPS-PPS Sampling Scheme:</u>

For Zone II, with photographs, the variable probability sampling design was used where sample units of two stages were all selected based on the Probability Proportional to Size (FPS). The size was the acreages of plantations estimated within the PSU and SSU units.

A generalized model for a two-stage estimator based on Langley (1975) is:

$$\hat{V}_t = \frac{1}{m} \sum_{i=1}^{m} \frac{V_i}{P_i} \quad \text{for the first stage,}$$

$$V_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \frac{V_{ij}}{P_{ij}} \quad \text{for the second stage,}$$

where:

$$P_i = \frac{X_i}{\sum_{i=1}^{M} X_i} \qquad P_{ij} = \frac{X_{ij}}{\sum_{j=1}^{N_i} X_{ij}},$$

P_{ij} is the conditional probability of drawing the jth SSU in the ith PSU.

X_{ij} is the forest acreage of one 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:

$$\text{Var } \hat{V}_t = \frac{1}{m(m-1)} \left(\sum_{i=1}^{m} \frac{V_i^2}{P_i^2} - m\hat{V}_t^{\,2} \right);$$

the terms are as defined before.

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 (Langley, 1969; Aldrich, 1971).

4.5.2 - SAMPLE SIZE (SAMPLING INTENSITY

The sample size should depend on the confidence level, allowable error, and the variance of the estimator to be used. Of the three variables involved, the allowable sampling error must be predetermined, the variability of the population parameter must be estimated or sampled, and the corresponding minimum size of the sample must be calculated from the first two variables. The sample size is calculated by:

$$n = \frac{t^2\ CV^2}{E^2},$$

where:

n = sample size,

t = normal deviation (two-sided) for a given confidence level,

CV = coefficient of variation of estimator,

E = 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 (Table 4.6).

For multistage sampling, sample size determination is not simple and additional assumptions and simplifications usually need to be made. But it still involves using the previous equation to relate sample size to the accuracy requirements and to the parameters for which inicial estimates are available (Harding and Scott, 1978).

In the two-stage sampling design, m primary sampling units (PSU's) were selected from the M primary units of Zone I or Zone II as a first stage.

From the selected m units, each one containing N_i secondary sampling units (SSU's), n_i SSU's were then chosen within each PSU. The details on the numbers used are shown in Table 4.6.

TABLE 4.6

SAMPLE INTENSITY OF ZONE I AND II FOR TIMBER VOLUME ESTIMATION

Class	CV % (1)	Sample size calculated		Planned Nº of SSU's in the second stage	Executed sample size in two stages			
		with E = 10% for First stage (2)	Second stage (3)		Zone I		Zone II	
					m	n	m	n
Pine	42	70	350	300	54	270	60	300
Eucalypt	36	50	250	250	55	275	57	285
Total	--	--	600	550	--	545	--	585

(1) Derived from a presampling field survey.

(2) Calculated by $n=t^2 \cdot CV^2/E^2$ with 95% confidence level for first stage.

(3) 5 SSU's per each PSU (equal number of SSU's per PSU).

As to sample allocation, the selection probabilities used in this project were equal probability and probability proporcional to size (PPS). Equal probability sampling was used in the second stage in Zone I where there was no available recent aerial photographs. In the first stage for Zone I and both stages for Zone II, it was used the probability porporcional to size. This procedure allows giving to the larger units higher selection probabilities, since they represent larger portions of the population. This was the reason for adopting the PPS selection system in the project. Both methods were performed with replacement.

4.6 - 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 Vertical Line Sampling method with the relaskop of Bitterlich (Husch et al., 1972; Loetsch et al., 1973 and Bitterlich, 1984).

$$V = \frac{1}{10} \; \Sigma \; dv^2 \; . \; FF,$$

$$G = \frac{1}{10} \; \Sigma \; dg,$$

$$Hm = \Sigma dv^2 / \Sigma dg,$$

where: V = stand mean volume in m^3/ha,

dv = diameter at 1.30m height of each tree included in vertical line sample for volume estimate,

FF = form factor of stand

G = basal area of stand m^2/ha,

dg = diameter at 1.30m height of each tree included in vertical line sample for basal area estimate.

Hm = mean stand height in m.

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 section 4.5.1.

The dendrometer measurements were entered in a Borroughs 6800 computer employed to handle the field data and to calculate the statistical parameters of the estimated total stand volume.

CHAPTER 5 - RESULTS AND DISCUSSION

5.1 - LEGEND AND KEY OF INTERPRETATION

According to the project's objectives, the vegetation types mapped were mainly pine and eucalypt plantations and natural forest. The establishment of this legend was very simple. As shown is Table 5.1, symbols for the main cover types were printed in colors to facilitate the distinction of each class.

TABLE 5.1

INTERPRETATION LEGEND

1. Eucalyptus spp. plantations: E. teriticornis, E. camaldulensis, E. globulus and E. grandis of different ages and characteristics are printed in blue color.

2. Pinus spp. plantations: P. pinaster, P. elliottii, P. taeda and P. insigne of different ages and characteristics are printed in red color.

3. Natural forest: all types of natural forest with more than 50% canopy or 200 trees by hectare are printed in green color.

4. Others: other species plantations, roads and raildroads, parks etc.

Table 5.2 shows a photointerpretation key for the three main classes using Landsat-TM imagery.

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 radition 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 or those for sheltering livestock and windbreak belts can easily be determined at the minimun area of one ha. 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 gray shadows.

4. Natural forests were usually found along drainages or on the hills.

5. Fairly homogeneous plantation areas of more than 4 ha 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 5.2

PHOTOINTERPRETATION KEY OF ANALYSIS

Class	Tone		Texture	
	Band 3	Band 4	Band 3	Band 4
Pine	DG	G to DG	F	MC
Eucalypt	G to DG	LG	F	F
Natural forest	G to DG	G	MC	MC

LG = Light grey
G = Grey
DG = Dark grey

F = Fine
MC = More coarse

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5.2 - THEMATIC MAPS

The final forest cover maps, which were prepared for printing, resulted from the interpretation of Landsat imagery. As stated in the proposal of this project (Novaes, 1986) forest cover maps for Uruguay were produced on two scales: 1:1 000 000 and 1:100 000. The final forest cover maps on the 1:100 000 scale were printed in black ink in three layers of overlays, one for each forest class: pine, eucalypt and natural forest, and a base map having the planimetric elements, totalizing 348 sheets. The forest cover map on the 1:1 000 000 scale makes no distinction between classes, and was produced in one sheet of lithographic film.

5.3 - INTERPRETATION AND MAPPING ACCURACY

The confusion matrices, as shown in Tables 5.3, were generated through visual interpretation results. They display the corresponding accuracies which were evaluated when compared with ground data from a field sample check.

In the process of obtaining the map accuracy and of determining the interpretation errors it was establised an 893 point sample as well as some other doubtful points to be verified in the field. More than 2/3 of those points were visited during the field work. This involved the re-examination of the Landsat images and the aerial photographs of Zone II.

Table 5.3 shows the overall interpretation and mapping accuracies which were 90,6 and 83,8 percent, respectively. Thus, the interpretation accuracies for pine and eucalypt are 82.4 percent and 95.5 percent respectively, and the mapping accuracies for pine and eucalypt are 81.9 percent and 81.4 percent, 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 plantations 4,5%.

The confidence intervals and the sampling errors of interpretation and thematic mapping accuraries were calculated by the equation of variance of $\bar{P}_i$ (Section 4.4.1). The results are shown in the following Table:

ACCURACY \ CLASS		PINE	EUCALYPT	NATURAL FOREST	OTHERS
INTERPRETATION	Confidence level	± 4.15 %	± 2.39 %	± 6.54 %	±2.49%
	Sampling error	5.04%	2.50 %	7.20 %	2.58 %
THEMATIC MAPPING	Confidence level	± 4.20 %	± 4.49%	± 8.25 %	± 4.82%
	Sampling error	5.13%	5.52 %	9.80%	5.62%

All accuracy requirements for each class of interpretation and thematic mapping were met (sampling error under 5%) except those for natural forest.

TABLE 5.4

CONFUSION MATRIX FOR ACCURACY ANALYSIS OF INTERPRETATION

THREE CLASSES

CLASS			FIELD CHECK		
			PLANTATIONS (PINE & EUC.)	NATURAL FOREST	OTHERS
IMAGE INTERPRETATION	PLANTATIONS		594	0	1
	NATURAL FOREST		0	69	6
	OTHERS		19	7	197
	TOTAL	Nº	613	76	204
		%	68.7	8.5	22.8
COMMISSION ERROR		Nº	1	6	26
		%	0.2	0.8	11.2
OMISSION ERROR		Nº	19	7	7
		%	3.2	9.2	3.4
INTERPRETATION ACCURACY %			96.9	90.8	96.6
THEMATIC MAPPING ACCURACY %			96.7	84.2	85.7
OVERALL INTERPRETATION ACCURACY %					96.3
OVERALL THEMATIC MAPPING ACCURACY %					89.0

TABLE 5.3

CONFUSION MATRIX FOR ACCURACY ANALYSIS OF INTERPRETATION

FOUR CLASSES

<table>
<tr><td colspan="3" rowspan="2">CLASS</td><td colspan="4">FIELD CHECK</td></tr>
<tr><td>PINE</td><td>EUCALYPT</td><td>NATURAL FOREST</td><td>OTHERS</td></tr>
<tr><td rowspan="6">IMAGE INTERPRETATION</td><td colspan="2">PINE</td><td>267</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td colspan="2">EUCALYPT</td><td>49</td><td>276</td><td>0</td><td>1</td></tr>
<tr><td colspan="2">NATURAL FOREST</td><td>0</td><td>0</td><td>69</td><td>6</td></tr>
<tr><td colspan="2">OTHERS</td><td>8</td><td>11</td><td>7</td><td>197</td></tr>
<tr><td rowspan="2">TOTAL</td><td>Nº</td><td>324</td><td>289</td><td>76</td><td>204</td></tr>
<tr><td>%</td><td>36.3</td><td>32.4</td><td>8.5</td><td>22.8</td></tr>
<tr><td colspan="2" rowspan="2">COMMISSION ERROR</td><td>Nº</td><td>2</td><td>50</td><td>6</td><td>26</td></tr>
<tr><td>%</td><td>0.7</td><td>15.3</td><td>8.0</td><td>11.7</td></tr>
<tr><td colspan="2" rowspan="2">OMISSION ERROR</td><td>Nº</td><td>57</td><td>13</td><td>7</td><td>7</td></tr>
<tr><td>%</td><td>17.6</td><td>4.5</td><td>9.2</td><td>3.4</td></tr>
<tr><td colspan="3">INTERPRETATION ACCURACY %</td><td>82.4</td><td>95.5</td><td>90.8</td><td>96.6</td></tr>
<tr><td colspan="3">THEMATIC MAPPING ACCURACY %</td><td>81.9</td><td>81.4</td><td>84.2</td><td>85.7</td></tr>
<tr><td colspan="6">OVERALL INTERPRETATION ACCURACY %</td><td>90.6</td></tr>
<tr><td colspan="6">OVERALL THEMATIC MAPPING ACCURACY %</td><td>83.8</td></tr>
</table>

By combining the results on pine with those on eucalypt, we may have a three-class confusion matrix table, as shown in Table 5.4. A comparison between the results of four classes (pine, eucalypt, natural forest and others) and three classes (plantation forest, natural forest and others) of the overall interpretation and mapping accuraries are:

OVERALL ACCURACY OF	FOUR CLASSES	THREE CLASSES	INCREASE
INTERPRETATION	90.6%	96.3%	5.7%
THEMATIC MAPPING	83.8%	89.0%	5.2%

It can be concluded that Landsat-TM imagery yields a classification of plantation forest and natural forest with very high percent accuracy.

5.4 - FOREST AREA

Table 5.5 presents the plantation areas for each class (pine, eucalypt and natural forest), by "Departamento".

TABLE 5.5

FOREST AREA PER "DEPARTAMENTO" IN URUGUAY (HA)

"DEPARTAMENTO"	PLANTATION FOREST			NATURAL FOREST	GRAND TOTAL
	PINE	EUCALYPT	SUBTOTAL		
ARTIGAS	8.64	5 804.16	5 812.80	49 374	55 186.80
CANELONES	1 595.12	6 190.32	7 785.44	4 757	12 542.44
CERRO LARGO	164.80	6 509.28	6 674.08	33 468	40 142.08
COLONIA	568.42	2 289.37	2 857,79	5 237	8. 094.79
DURAZNO	199.76	6 687.50	6 887.26	11 666	18 553,26
FLORES	-	2 335.04	2 335.04	3 305	5 640.04
FLORIDA	84.20	7 115.76	7 199.96	14 909	22 108.96
LAVALLEJA	115.52	6 817.86	6 933.38	32 284	39,217.38
MALDONADO	1 475.48	4 692.16	6 167.64	16 878	23 045.64
MONTEVIDEO	585.44	677.96	1 263.40	102	1 365.40
PAYSANDÚ	2 772.72	9 804.68	12 577.40	46 338	58 915.40
RIO NEGRO	1 442.80	6 137.38	7 580.18	10 455	18 035.18
RIVERA	1 620.96	8 081.73	9 702.69	24 650	34 352.69
ROCHA	7 213.06	6 570.32	13 783.38	19 454	33 237.38
SALTO	17.44	5 777.31	5 794.75	41 286	47 080.75
SAN JOSE	1 065.64	2 480.32	3 545.96	6 122	9 667.96
SORIANO	-	3 423.78	3 423.78	7 323	10 746.78
TACUAREMBÓ	930.36	8 270.58	9 200.94	47 643	56 843.94
TREINTA Y TRES	23.68	4 117.82	4 141.50	22 981	27 122.50
TOTAL	19 884.04	103 783.33	123 667.37	398 232	521 899.37

Uruguay has a total area of 176,027 square kilometers, and according to this project we can conclude that the total forest area is only about 3% of the total land area in Uruguay, as shown in Table 5.6. The plantation forest, (pine and eucalypt) is about 23.67% of the total forested area.

Natural forests are concentrated basically along rivers and drainages.

In Uruguay, most 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.

TABLE 5.6

SUMMARY OF FOREST AREA

Area of Uruguay	Area of Forest Land				
	Plantation Forest			Natural Forest	Total
	Pine	Eucalypt	Subtotal		
17,602,700	19 692	103 784	123 667	398 232	524 899
100%	0.1%	0.6%	0.7%	2.3%	3.0%
-	3.8%	19.9%	23.7%	76.3%	100%

Forest area per "Departamento" in Uruguay was the result of interpretation of Landsat-TM. This includes forest areas planted prior to 1985.

Areas of parks, such as Santa Teresa and San Miguel, are not included. The areas of pine/eucalypt plantations do not include areas of others species, such as salix, populus spp. and palma.

5.5 - VOLUMETRIC RESULTS

5.5.1 - STATISTICAL RESULTS

The statistical results of the total stand timber volume for Zone I and II are presented in Table 5.7. The form factor used for pine plantations was 0.45 and for eucalypt plantations was 0.50.

5.5.2 - MEAN STAND TIMBER VOLUME

Table 5.8 shows the mean stand timber volume which were calculated using different form factor.

TABLE 5.8

MEAN STAND TIMBER VOLUME WITH DIFFERENT METHOD AND DIFFERENT STAND FORM FACTOR (m^3/ha)

ZONE	I		II	
METHOD	Two-stage with PPS-SRS		Two-stage with PPS-PPS	
SFF \ CLASS	Pine	Eucalypt	Pine	Eucalypt
0,50	161,49	243,64	250,43	217,57
0,45	145,34	219,27	225,38	195,81
0,40	129,19	194,91	200,34	174,06
0,30	96,89	146.18	150.26	130.54

PPS: Probability Proporcional to Size
SRS: Simple Randon Sampling
FF: Form Factor

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TABLE 5.7

THE STATISTICAL RESULTS OF THE ESTIMATED TOTAL TIMBER VOLUME

ZONE	I		II	
METHOD	Two-stage with PPS-SRS scheme		Two-stage with PPS-PPS scheme	
CLASS	Pine	Eucalypt	Pine	Eucalypt
FORM FACTOR	0,45	0,50	0,45	0.50
Total timber volume m³	1 710 608.20	15 429 409.34	1 828 809.95	8 801 709.49
Standard error m³	140 002.10	1 933 835.94	199 320.85	855 837.62
Relative standard error %	8.18	12.53	10.90	9.72
Upper 95% confidence limit	1 985 012.32	19 219 727.78	2 176 275.98	10 537 951.71
Lower 95% confidence limit	1 436 203.88	11 639 090.90	1 438 140.98	7 065 467.71
Relative confidence interval %	± 16.03	± 24.56	± 21.36	± 19.06
Mean timber volume with its confidence interval (m³/ha)	145.34 ± 23.30	243.64 ± 59.84	225.38 ± 48.14	217.57 ± 41.47

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Table 5.10 presents the stand timber volume per "Departamento" in cubic meter. The data on forest acreage in Table 5.5 and the mean stand timber volume in Table 5.9 were used to calculate those data.

TABLE 5.9

MEAN STAND TIMBER VOLUME OF PINE AND EUCALYPT FOR ZONES I AND II

ZONE \ FF \ CLASS	Pine	Eucalypt
	0.45	0.50
I	145.34 m^3/ha	243.64 m^3/ha
II	225.38 m^3/ha	217.57 m^3/ha

The stand timber volume of Pinus spp. and Eucalyptus spp.plantations in the whole country were estimated as 3.539 cubic meters and 24 231 118,83 cubic meters, respectivelly (Tables 5.7 and 5.10).

TABLE 5.11

SUMMARY OF THE TOTAL STAND TIMBER VOLUME RESULTS FOR THE WHOLE COUNTRY

Class	Pine	Eucalypt
Total Timber Volume	3 539 418.15 m^3	24 231 118.83 m^3
Mean Timber Volume	178.00 m^3/ha	233.47 m^3/ha

TABLE 5.10

STAND TIMBER VOLUME PER "DEPARTAMENTO" (m^3)

"DEPARTAMENTO"	ZONE	PINE (SFF= 0.45)	EUCALYPT (SFF = 0.50)	TOTAL
ARTIGAS	I	1 255.74	1 414 125.54	1 415 381.28
CANELONES	II	359 508.15	1 346 827.92	1 706 336.07
CERRO LARGO	I	23 952.03	1 585 920.98	1 609 873.01
COLONIA	II	86 963.96	368 214.27	455 178.23
DURAZNO	I	29 033.12	1 629 342.50	1 658 375.62
FLORES	II	-	508 034.65	508 034.65
FLORIDA	II	18 977.00	1 548 175.90	1 567 152.90
LAVALLEJA	I	16 789.68	1 661 103.41	1 677 893.09
MALDONADO	I	214 446.26	1 143 197.86	1 357 644.12
MONTEVIDEO	II	131 946.47	147 503.76	279 450.22
PAYSANDÚ	II	624 915.63	2 133 204.23	2 758 119.86
RIO NEGRO	II	325 178.26	1 335 309.77	1 660 488.03
RIVERA	I	235 590.33	1 969 032.70	2 204 623.02
ROCHA	I	1 048 346.14	1 600 792.77	2 649 138.91
SALTO	I	2 534.73	1 407 583.81	1 410 118.54
SAN JOSE	II	240 173.94	539 643.22	779 817.16
SORIANO	II	-	744 911.81	744 911.81
TACUAREMBÓ	I	135 218.52	2 015 044.11	2 150 262.63
TREINTA Y TRES	I	3 441.65	1 003 265.67	1 006 707.32
TOTAL		3 539 418.15	24 231 118.83	27 770 536.98
PERCENT OF VOLUME		12.75%	87.25%	100.00%

SFF = STAND FORM FACTOR

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

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

6.1 - CONCLUSIONS

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-TM images.

2. The characteristics of forest classes may be recognized using combinations of tone, texture, shape and size in two spectral bands of Landsat TM imagery (3 and 4). Band 5, when available, is also useful.

3. Sometimes, it was difficult to distinguish between pine and eucalypt plantations, without complementary ground data.

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

5. The restricted and acceptable quality of the images for apropriate dates restrains their applications. It was not possible to obtain free of cloud images of the path/row 223/84 and 224/84 in the period from May 2, 1985 to July 12, 1985.

6. The areas measured using Landsat images and areas measured using aerial photographs in this project were sometimes very different due to difference from three to five years between these material.

7. Visual interpretation is a very simple and efficient methodology for mapping forest land using Landsat-TM imagery on the 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 83.8 percent, respectively.

8. On the 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.

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

10. One of the constraints found in the application of a two-stage sampling design for Zone II was the utilization of aerial photographs obtained during the 1980 and 1982 periods. This was the most recent aerial survey available for the country. During the field work a significant difference between the informations obtained from the photographs and those obtained on the ground was verifield. Most the Landsat images were used as an aid to the aerial photos, when the methodology applied in this project required the use of the aerial photographs to help and improve the informations obtained from the satellite imagery.

11. For the second stage, the methodology used for the volumetric measurements in the field (Strand method) resulted simple and fast for that kind of inventory, because it was not necessary to delineate the sample plots (SSU).

12. The theoretical basis of the method presumed ordained and homogenous plantations which was not always verified in the field. For this reason, sometimes, the procedure in the field work was impaired. The most inadequate application of the method was on the sandy dune and coast

plantations, on natural regeneration zones and on certain associated eucalypt plantations.

13. The Strand's Vertical 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 550, the method employed could not be a good estimator of basal area, heigt and volume of a single SSU just four measurements.

14. The sampling erros obtained in this work are acceptable since it deals with a reconnaissance and extensive inventory. The high values found in certain cases are surely due to the great variability of the analised forest population, as age, species site and different management conditions.

15. Considering the objective of the Uruguayan specialists training course, although it hasn't made any evaluation of individual performances, one can conclude, based on observations done during the course, on the field works and also on the job training held in Brazil, that the results were very satistactory.

6.2 - RECOMENDATIONS

1. Four different values of Form Factor were used to calculate the volume of pine and eucalypt because there are no acceptable and general data on Form Factor for these species in the country. In the future, when an accurate mean value for the country becomes available,the results obtained in this project should be revised.

2. It is very important to have a good understanding of the spectral characteristics of different forest land features in the Landsat imagery, in order to carry out the interpretation more efficiently and make reliable decisions during the interpretation process.

3. Multidate imagery and color composite imagery are likely to improve significantly the interpretation accuracy of plantation forest types as it allows a better distinction among forest classes.

4. Based on previous experiences, computer-aided classification may provide an improvement in forest cover mapping and inventory in terms of time, cost and accuracy, especially at a national level. It is suggested to investigate the operacional use of automatic classification in similar works in the future.

5. 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.

6. Following to literature on the adopted methodology, the maximum permissible sampling error established in the preliminary sampling applied on the basal area variable. Based on the results obtained and on the final sampling error calculated, it is suggested, for future works, a pre-sampling of volume, since the mean height of the trees proved to be a very important source of variation.

7. 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.

8. The final recommendation for the Uruguayan Government, is the establishment of a permanent group to conduct forest cover mapping and timber inventory activities using satellite imagery (Landsat and Spot).

CHAPTER 7 - TRAINING ACTIVITIES

In January, 1986, a training course was accomphished whose objective was to present the remote sensing technology applied to image interpretation and forest resources mapping. It was held in Montevideo, Uruguay, in the Military Geographic Service, for Uruguayan technicians, in the period from January 21 to 30.

The Institute for Space Research of the Science and Tecnology Ministry was responsible for the course named "TM/LANDSAT Data Applied to Forest Cover Mapping and Land Use". This course was taught by the Economist René Antonio Novaes and Forest Engineers Pedro Hernandez Filho, Armando Pacheco dos Santos and David Chung Liang Lee.

The course was predominantly practical, with thirty-two-hours of theoretical and practical classes, and a three-day field work inside the country.

The following agencies and technicians, from Uruguay, attendend the course:

Energy and Industry Ministry:

. Agr. Forest Eng. Rosario Pou Ferrari
. Agr. Forest Eng. Gerardo Almeida Demarco
. Agr. Forest Eng. Gustavo Gamundi
. Agr. Forest Eng. Carlos Blasi Serrano

Fishery and Agriculture Ministry

. Agr. Forest Eng. Peter U. Baptista Palaez
. Forest Technician Francisco de Castro Silva

Faculty of Agronomy - Uruguay University

. Agr. Forest Eng. Arianna Sorrentino
. Agr. Forest Eng. Hugo Antunez *

Military Geographic Service - Ministry of Defense

. Lieutenant Edilberto Viar
. Mr. Romulo Gerra *

* They did not take part in the field work.

The program of the course was the following:

- First day:

. Introducion to the fundamentals of Remote Sensing.
. Sensor systems and products of Landsat and Spot.
. Visual interpretation methodology using TM/LANDSAT for forest cover mapping and land use.

- Second, third and forth days:

. On the job training in image interpretation and exercises. Each participant accomplished individual work of image interpretation using the TM/LANDSAT prints, on the 1:100 000 scale, 222/84 path/row, of May 4, 1985, band 3, 4 and 5. Using the overlays of the image interpretation and the topographic map, on the 1:100 000 scale, from Uruguay, the field work was planned. The main objective of this field work was to check the identification of Pine and Eucalypt results, acreage and volumetric mensuration practice.

- Fifth, sixth and seventh days:

. A field work between the cities of San Carlos and La Paloma was accomplished within the Maldonado and Rocha "Departamentos", around roads 9 and 10. Observations and mensurations of genus and species, basal area and wood volume using the Bitterlich relaskop (Bitterlich-Strand Method), and the rangefinder for area mensuration, were carried out on 22 forest plantations.

- Eight and last day:

. Discussions integration of the field work data and course evaluation took place in last day.

Continuing the training course, two more phases were accomphished in São José dos Campos, Brazil, involving two Uruguayan technicians: Forest Eng. Peter U. Baptista Pelaez from the Fishery and Agriculture Ministry and Lieutenant Edilberto Viar From the Military Geographic Service.

Both researchers visited INPE's facilities in Cachoeira Paulista, where they were able to observe all the processes involved in the acquisition and transformation of the Landsat satellite data.

In the March 5th - 12th period, the agronomist-forestry engineer Rosario Pou participated in the technical discussions on the methodological aspects and the progress of the project. She also colaborated in the interpretation key determination for species discrimination in the preliminary interpretation process.

The second phase occurred in the period from June 2nd to 28th, 1986. Mr. Baptista and Lt. Edilberto worked in the data interpretation and sample size definition for the second field work.

Mr. Baptista participated in the following activities: estimation of forestland acreage sample size; determination and allocation of the primary and secondary sampling unities with equal probability and probability proportional to size; data integration of the multistage sampling system applied to forest inventory and preparation of the second field work.

Lt. Edilberto Viar participated in the process of forest themes representation in maps on the scales of 1:100 000 and 1:1 000 000.

During the period from December 8th, 1986 to January 30 th, 1987,the agronomist-engineer Ariana Sorrentino took part in the following activities: volumetric data processing; discussion of the project results; composition of the final report and the spanish translation.

Although formal evaluation of the participants in the training course has not been made, it was felt that, in general, all the uruguayan technicians had a satisfactory experience.

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