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16. Summary/Notes <i>In this paper an overview of the utilization of satellite remote sensing in Forestry is presented. The application studies that have been performed for the Brazilian Amazon Region are described. They include the mapping, the deforestation and the evaluation of pasture degradation after deforestation of the Amazon Forest.</i>			
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REMOTE SENSING IN FORESTRY:
APPLICATION TO THE AMAZON REGION

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CHAPTER I

INTRODUCTION

The aim of this paper is first to present general information about the utilization of satellite remote sensing in forestry and second to discuss the applications that have been developed especially in the Brazilian Amazon region.

The intention here is not to treat the technicality involved in the application of remote sensing, but to give to the reader the basic knowledge about what has been done and can be done in that important area.

The characterization, mapping, inventory, management and monitoring of natural and artificial forest lands are important information for a country that possesses them, mainly to the economical aspects involved.

Wood and paper production have been the most common utilization of commercial forest trees. However, in countries like Brazil - where there is an oil deficit - as a consequence of the energy crisis, programs are now under way in order to utilize wood for charcoal and alcohol production. Fruits and leaves of some forest species can also be used to produce oil.

Modifications that take place in a large natural forest can, as a consequence, introduce global environmental variations. Uncontrolled deforestation in the Amazon Forest, for example, may cause drastic changes in the world climate.

In order to meet the requirements mentioned above, it is necessary that the methodology to be used has to have the following properties:

- can be applied to extense areas
- has a low cost/benefit ratio
- has an intrinsic dynamical character

And the methodology derived from satellite remote sensing data have them as basic characteristics, thus giving to space application technology an useful and important utilization.

CHAPTER II

REMOTE SENSING APPLIED TO FORESTRY

2.1 - SPECTRAL CHARACTERIZATION OF VEGETATION

Because the main source of data is derived from the electromagnetic radiation reflected and/or emitted by the Earth's surface and detected by sensor devices, it is important to know first how vegetation interacts with solar radiation. Figure II.1 presents the average spectral response of a green leaf (after Hoffer and Johannsen, 1972).

It can be observed that there is an absorption band in the 400-700 nm region (which is mainly due to pigments, especially chlorophyll) and a reflection band in the 700-1,300 nm part of the spectrum (which is related to the morphological structure of the leaf). The reflectance in the 1,300-2,600 nm region is highly influentiated by the presence of water. For example, the two absorption bands (1,400-1,500 nm and 1,900-2,000 nm) are characteristic features of the absorption spectrum of water.

The effect of the vegetation multiple leaf layers and the density of its coverage is then to produce a high reflectance and a low absorption in the infrared portion of the spectrum when compared with the visible part of it.

However, the radiation detected by the remote sensors are not associated only with the intrinsic characteristics of vegetation, but also with other factors as climate, soil and topography.

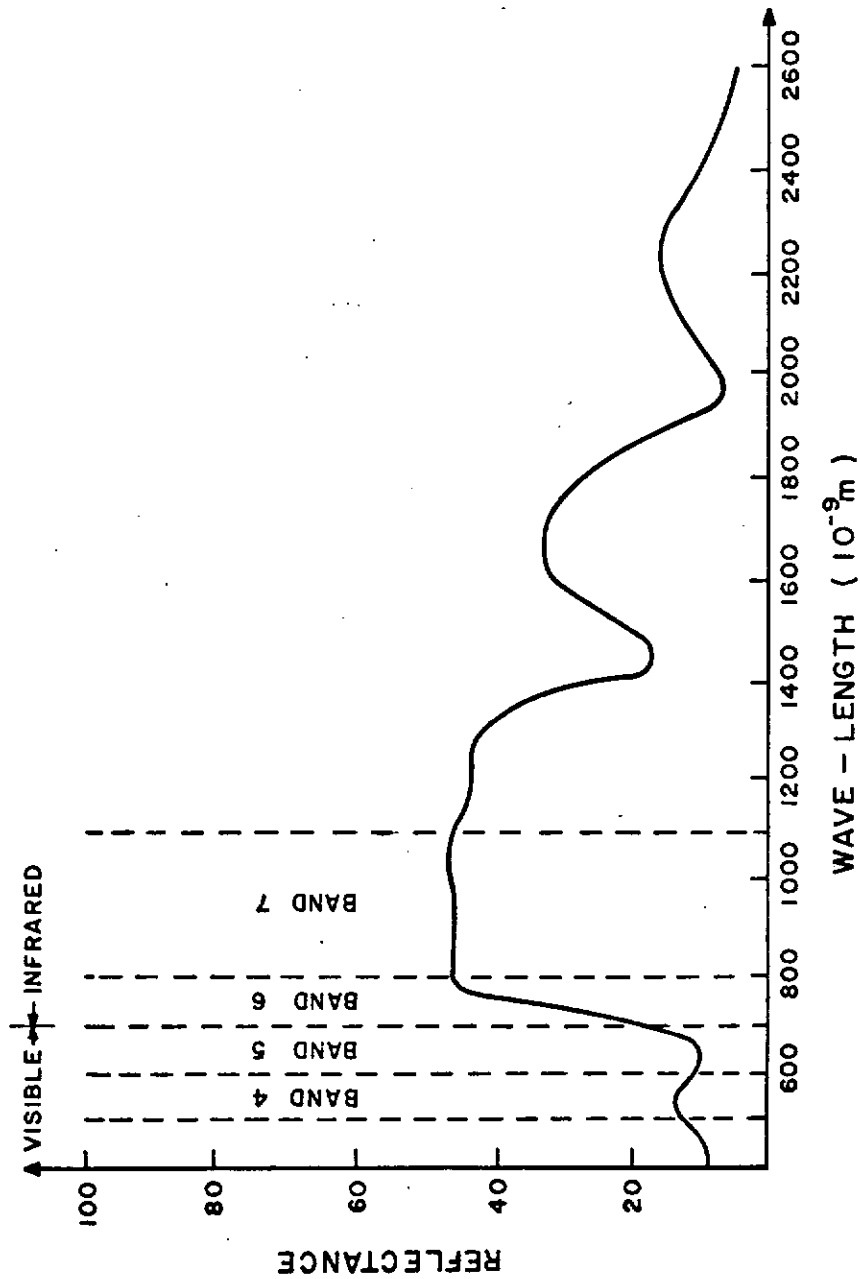


Fig. II.1 - Average spectral response of vegetation (green leaf).

● Climatic Factors

Meteorological factors play an important role in the spectral responses of vegetation on LANDSAT imagery. To test and improve vegetation classification, remote sensing data of different seasons should be used (Weber et al., 1972; Kan and Dilman, 1975; Safir et al., 1973).

Classification accuracy depends on the season during which data are taken and analysed. Borden et al. (1974) concluded that data of two seasons, spring and winter, could be used for discrimination of conifer and broad-leaf species. Kan and Dilman (1975) used channels 5 and 7 MSS data obtained at two different seasons (spring and winter), to separate needle-leaves evergreen species and broad-leaved deciduous. Valério Filho et al. (1976) studied different vegetation units of the Mato Grosso do Sul State and showed that the differences were enhanced, when data of the dry and rainy seasons were compared. Santos and Novo (1977) used dry season imagery and concluded that identification of vegetation was easier to be done because it has different root depths.

Correlations between the climatic factors and phenological stages of vegetation and other influences on the LANDSAT imagery were reported by Lauer (1964), Wilianson (1973), Wiegand et al. (1973), Ashley and Dethier (1973) and Smith and Nobel (1977).

● Soil Factors

Soil and vegetation are two factors which influence the quantity of solar energy reaching or being absorbed by the soil (Myers and Heilman, 1969). If vegetation coverage is the dominant factor then the knowledge of the relationship between soil and plant indicate the soil condition (Hilwi et al., 1974). LANDSAT sensors record the radiance of a soil/plant complex and the vegetation coverage may

disguise the soil spectral response (Siegal and Goetz, 1977). Wong et al. (1977) reported that the soil characteristics are correlated with vegetation, climate and topography, among other factors.

The spatial and temporal characters of LANDSAT data are very useful in the study of the soil/plant relationship. Westin and Mayers (1973) analysed data related to vegetation in different seasons and phenological stages and associated the information with the under-forest soil type. Based on the spectral responses of vegetation, Parkes and Bordenheiman (1973) delineated three different soil associations in Tennessee State, USA.

- Physiographic Factors

Maxwell (1975a) reported that soil condition monitoring depends on the information about vegetation and topography. This result was also reported by Wong et al. (1977) and used as a factor in soil formation, and should be considered in the multispectral analysis techniques. Strahler (1975) studied the relation among drainage density, vegetation and topography, and concluded that in gently undulated area where the drainage density is low, the vegetation cover is usually dense.

King and Rains (1974) showed that channel 7 LANDSAT images reveal topographic conditions of areas covered by forest.

For Schrumpf (1973) natural vegetation could be identified on LANDSAT-1 images, based on the physical characteristics of the terrain, such as relief, soil, drainage density and parent material.

Santos (1976) studied the vegetation of the Southern part of Espirito Santo State, using channel 5 and 6 LANDSAT MSS imagery and noted the occurrence of shrub and arboreal vegetation in areas of flat to gently undulated relief and forests in areas of rolling relief.

2.2 - REMOTE SENSING DATA AVAILABLE

There are different types of sensor devices used in remote sensing applications. Consequently, the corresponding data depend on the device properties, including range of frequencies detected (microwave, visible, infrared, etc) and on the type of platform used for transporting it (airplane, satellite, etc).

The most common data available are aerial photography (visible, infrared, microwave) and Earth observation satellite imagery (visible and infrared). But, ground truth information is of great importance when calibrating the airborne and satellite data.

For each electromagnetic spectral range a specific sensor can be used (Figure II.2). The selection of a proper sensor depends on the:

- 1 - purpose of the application;
- 2 - requirement for geometric resolution;
- 3 - required spectral resolution;
- 4 - required scale;
- 5 - climatic conditions;
- 6 - economic restrictions;
- 7 - characteristics of the platform.

Even though an orbital sensor such as LANDSAT has high initial cost, it permits the data acquisition at a low cost per unit area, owing to its large area coverage and repetivity. The lower the sensor altitude, the higher the cost of the survey.

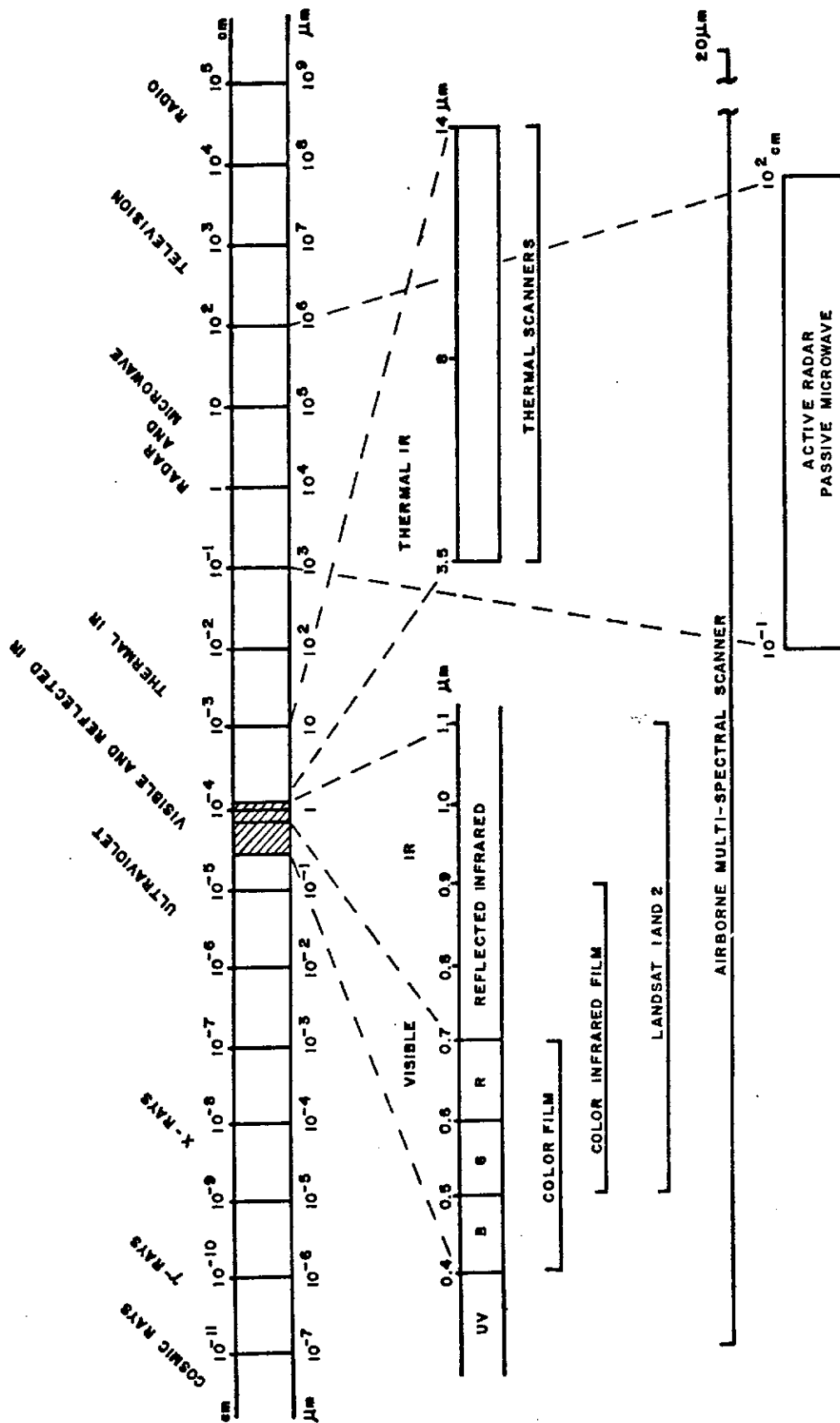


Fig. II.2 - The Electromagnetic Spectrum with Spectral Ranges of Some Common Remote Sensing Systems.
 From: Harding and Scott (1978), p. 110

Although the methodology used in each application may be different, there are some common aspects that should be considered, when selecting the appropriate remote sensing data:

- temporal characteristics
- spectral characteristics
- scale used

For satellite remote sensing data, the first aspect is important and is related to the seasonal variation presented by vegetation. It is known that during the rainy season there is a tendency of the vegetal coverage to become more homogeneous, because the deciduous species recover their foliage and the stressed species (due to the lack of water) recover their vigour. However, it is in the dry period that vegetation present great differences in the spectral response, allowing for a better identification of the species and sometimes for the discrimination between different shapes within the same specie. So, dry season data are recommended when it is not possible to sequentially obtain them. However, data related to the rainy season is also relevant in the interpretation techniques.

Now, as the four LANDSAT MSS bands cover the 500-1,100 nm spectral region, they can be used in forest applications. Although the four channels furnish useful information, several studies already done show that channel 5 and 7 are the best ones to be used in the identification of different types of vegetal coverage (this can be easily understood, because channel 5 includes an absorption band and channel 7 a reflection band).

The more dense the vegetation, the more its electromagnetic energy absorption rate is. So, both channel 4 and 5 data can be used for this purpose, but channel 5 presents a better contrast, allowing for small variations on the vegetal coverage to be visually detected. Also, channel 7 data is very useful to identify vegetal coverage types affected by soil humidity, because the vegetation water content reduces its reflectance.

Generally speaking, the use of coloured compositions helps the identification of any target. For vegetation, infrared false color compositions (bands 4,5 and 7) are useful, since they enhance the existing different types of vegetation from the dark-red (areas of dense coverage) till tonalities near the yellow (areas of exposed soil). In a colour image it is possible to extract much more information than in a black and white image, due to the higher sensibility of human eyes to colours than to gray tones.

As far as the scale is concerned, 1:500,000 and 1:250,000 images are strongly recommended for visual interpretation.

2.3 - INTERPRETATION PROCEDURES

Image interpretation is based on the type of vegetation (natural or reforested) covering the study area and its spectral, spatial and temporal properties. For spectral analysis the elements texture and tonality are used. For temporal analysis the spectral characteristics of the data acquired at different dates are compared and for spatial analysis, form and distribution in space are analysed.

Only images of channel 5 and 7 are used in visual interpretation, because they present sufficient information to characterize vegetation. As mentioned before, when compared with sparse vegetation, dense vegetation presents in channel 5 a darker tone and in channel 7 a lighter one. Areas of low vegetation density and high soil moisture may present dark tone in channel 7 due to water absorption.

Another element that can be used in photo interpretation is texture, which presents the variation in grey level of each mapping unit. It can be divided into three categories: fine, medium and coarse textures. Fine texture is assigned when no variation in grey level is observed, and a mapping unit has coarse texture when a large

variation exists. In channel 5, homogeneously grown reforested area presents a fine texture while heterogeneous reforestation presents a coarse texture due to spatial discontinuity. In channel 7 coarse texture is related to the difference of species or age groups.

For computer-aided classification, the analysis procedure can be separated into three parts:

- 1) definition of which classes of different vegetal coverage are to be distinguished;
- 2) utilization of the characteristics of each class for discrimination, and
- 3) establishment of a decision method to define which class the analysed element belongs to (Goodenough and Shilien, 1974).

The definition of the forest classes that can be computer analysed is obtained throughout the analysis of detailed information about the study area. These information are provided by aerial photography and or/field data. The characteristics of each class are obtained using data of the four LANDSAT MSS bands. At INPE, the computer-aided classification of LANDSAT MSS data stored in computer compatible tapes (CCT's) is carried out using a GE IMAGE-100 system and a Bendix MDAS system. The procedures that should be taken in the analysis are the following:

- a) study area preparation: here the study area is enlarged on the image monitor and its boundary delimited;
- b) classification of the study area: using the electronic cursor, several samples can be selected in the study area; they are used to train the computer for classification. Two Image-100 classification options are often used for forest study: the

single-cell and the MAXVER algorithms. Detailed description of these algorithms can be found in Velasco et al. (1978).

- c) evaluation of the results: after the classification is done the results should be quantitatively evaluated, first by visual observation of the classes classified on the image monitor and after by a pixel-by-pixel comparison between the classification results and the independent reference data. As a consequence a confusion matrix can be constructed, where the errors of commission and omission and the percentage of correct classification for each class are presented. These percentages give an idea about mapping accuracy.

For forest mapping, inventory or management studies it is important to analyse spectral, temporal and spatial (scale) characteristics of the remote sensing data. Field information is also required for a successful inventory study which includes: detection of the modification caused by deforestation, forest fire, or insect disease infestation; mapping of reforestation and monitoring of natural park or reserves.

2.4 - SOME SATELLITE REMOTE SENSING APPLICATIONS

2.4.1 - INTRODUCTION

Before going to next Chapter, where the methodology developed for the utilization of remote sensing technology in the Amazon Forest will be analysed, it is interesting to briefly discuss other satellite remote sensing applications on forestry, in order for the reader to have a reasonable view about what have been done in this area. Preferable, when pertinent and available, examples developed for South-America will be presented.

According to the nature of the problem under study, the utilization of remote sensing information in forestry can fall in one of the following categories:

- characterization and/or mapping
- inventory and/or assesment
- management and/or monitoring

of natural and artificial forest lands.

When mapping forest, data provided by sensores aboard airplane or orbital platforms are used. Homogeneous units are mapped according to their tonality, texture, hue and field data.

Forest inventory provides volume estimation (based on forest maps), information that is necessary for management planning and production controll.

Forest management involves planning and decission making to assure continous and regular obtention of prime material. Real time information about the damages caused by insects, diseases, forest fire, deforestation, frost and other agents are important decision factors in the process.

According to the characteristics of the trees, Ghilardi and Mainieri (1964) divided the commercial wood into two groups; conifer and broad leaved trees. In Brazil the most widely used conifer species are the Parana pines (*Araucaria angustifolia*). They can be used for construction, packing and plywood. One example of a broad-leaved forest is the Amazon Forest. The utilization of the broad-leaved trees is more ample, including construction and packing. The oil extracted from broad-leaved wood can be used for perfume or varnish.

Reforestation in Brazil is predominantly done with *Pinus* and *Eucalyptus* spp. and their main utilization is for cellulose paper production. But they are also used for plywood and to produce colophony and turpentine oil. Studies for their utilization as alcohol prime matter are now under way.

2.4.2 - NATURAL VEGETATION APPLICATIONS

It has been possible, by using satellite remote sensing imagery to identify and to map natural forests and to classify them on some general categories as, for example, dense forest and open forest.

One of the first works about the application of orbital images (LANDSAT) in natural forest mapping in Brazil was done by INPE in cooperation with the Centro de Pesquisas Florestais (Forest Research Center) of the Paraná State University (1974). The objective of the work was to map the forest coverage of the Parana State in order to update the available existing data. (region nº 1 on Figure II.3).

The final Parana State forest coverage map served as a basis to evaluate the forest prime material of the State, since there was no updated survey data, due to an accelerated process of exploration, to which the Paraná State forest reserves were submitted.

The work was done with LANDSAT images, channels 5 and 7, at the scale of 1:250,000, dated 1973, totalizing 14 images. The resulting map presented a forest coverage of the State, where the distinction was only made between areas with and without forest formation. It allowed the State Government to know the existing Paraná State forest coverage (15%), as well as the flow of devastation.

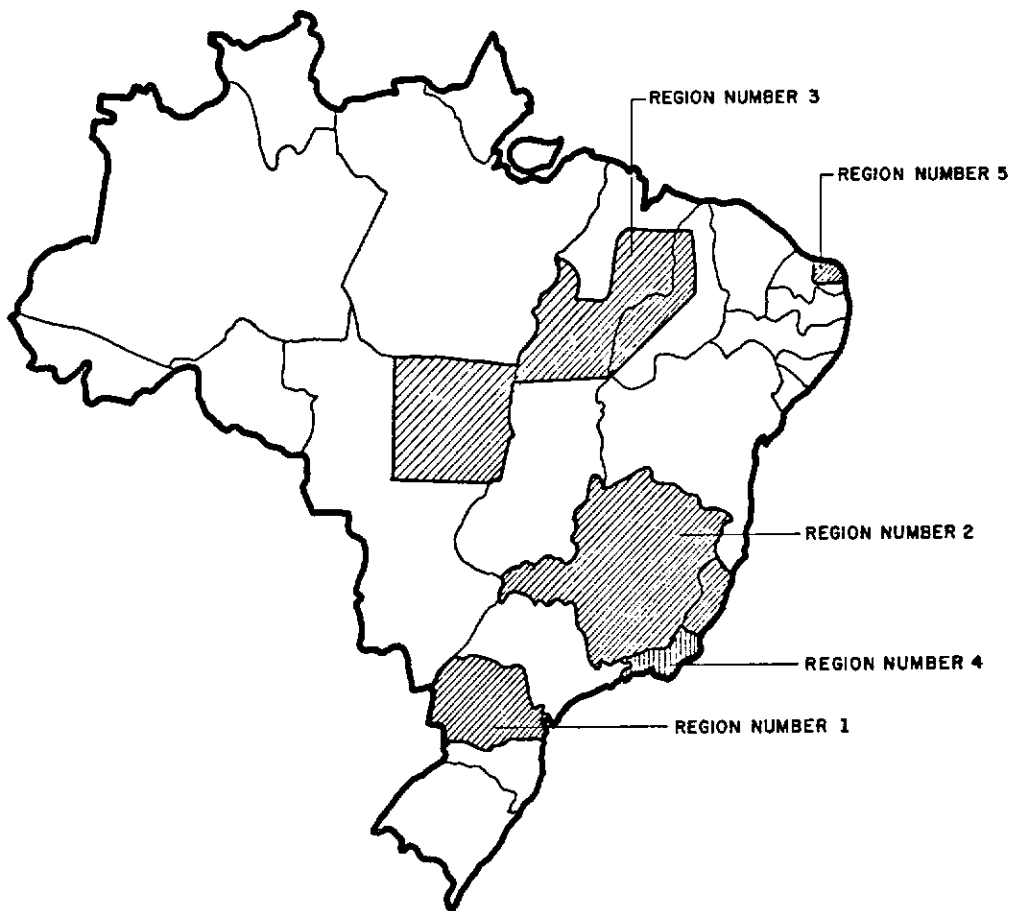


Fig. II.3 - Natural Vegetation Applications study Areas.

Another work carried out with LANDSAT data was the natural vegetation mapping of the States of Minas Gerais and Espírito Santo (region nº 2 on Figure II.3) comprising an area of 622,616 km². (Nosseir et alli., 1975). The objective of the work was to furnish a map of the primitive vegetation of these two States and to establish a methodology for the utilization of MSS data in the vegetal coverage survey.

LANDSAT images at the scale of 1:1,000,000, in the four MSS bands, totalizing 33 images, were utilized, and the visual interpretation was based on spectral responses of the different types of vegetation.

The legend developed in this work was based on the following ecologic parameters; physiognomy of field vegetation, climate of the regions, vegetation morphology and geomorphology.

Later, with the objective of developing a methodology for the utilization of LANDSAT images in the identification of babaçu* forests, another project was performed.

The studied region included part of the States of Maranhão, Piauí, Mato Grosso and Goiás, where this type of vegetation occurs in an approximate area of 12 to 15 million of hectares (region nº 3 on Figure II.3).

The work was done by the state agencies involved, and INPE was responsible for training courses on LANDSAT images interpretation and technical assistance to the project.

* *Babaçu is a natural type of vegetation (trees) used for oil production in Brazil.*

Visual interpretation of LANDSAT images, at the scale 1:500,000, channels 5 and 7, based on tonality and texture criteria of the different vegetation types was performed. The legend included different types of babaçu occurrences, i.e., dense babaçu, medium dense babaçu and sparse babaçu. This division was necessary because the babaçu productivity varies with the type of occurrence.

Based on the area survey, productivity studies were done for the areas with greater occurrence of babaçu to verify the economic viability of its exploration.

The Rio de Janeiro State (region nº 4 on Figure II.3) with a surface area of 44,268 km², have, until 1979, no updated coverage with aerial photography that could provide important information about its actual natural vegetation coverage.

In 1977, FEEMA (State Environment Foundation), based on LANDSAT images, carried out a project in order to map the remanescent forest of that State. The results showed that 17% of the whole State was forest covered.

These results were checked out in 1978 by FEEMA in cooperation with INPE. LANDSAT CCT's tapes were interpreted by using the Image-100 and automatic classification. It was concluded that 22% of the State was covered with forest which included:

- Remanescent forest
- Dense regenerated forest
- Arboreal vegetation
- Artificial forest
- Mangrove

One of the first work to map natural resources using remote sensing methodologies in a integrated way was carried out by Foresti et al. (1978).

This methodology was applied to the survey of an area of 1,500 km² located in the Southeast of Rio Grande do Norte State (region nº 5 on Figure II.3). The principal elements used were geology, geomorphology and land use, which were associated to climate data.

The thematic maps were obtained from visual interpretation of black and white LANDSAT images, channels 5 and 7, at the scale of 1:250.000. The visual analysis of LANDSAT images was based on the textural and tonal criteria besides the geomorphic features and drainage patterns.

Eighteen land use units were mapped: very sparse vegetation along the seashore; dune vegetation (including shrub and arbored vegetation); mangrove; agricultural areas, and forest. Within the forest area categories were discriminated: gallery forest with the presence of carnauba (*Copernicia bruniifera* Mill.) trees; primitive and secondary forest; arboreal caatinga; shrub caatinga; sparse shrub caatinga; dry caatinga and semi desertic caatinga. Three vegetation zones were separated in the study region: forest zone, agrest zone and sertão zone.

The forest zone was mainly characterized by the occurrence of forest more dense than in the other zones. But in small areas, sparse vegetation along the sea shore, dunes, mangroves, cerrado * and campos ** were also present.

The agreste zone is occupied principally by caatinga, while the sertão zone presents a more sparse caatinga than the agreste zone.

* Cerrado is a natural vegetation of central part of Brazil.

** Grassland.

Another work dealt with the mapping of Cerrado vegetation in Central Brazil occupying an area of approximately 1,500,000 km². The landscape Cerrado is predominant of flat and gently undulated relief, which is suitable for agricultural mechanization, silviculture and grazing land uses.

Due to the governmental policy of interiorization, the Cerrado region is experiencing an increasing exploitation. An understanding of the distribution and extension of the region resources, for their rational integration into the country's socio-economic development process, is becoming indispensable.

Considering that the characterization of vegetation is fundamental to the problems of rational use and exploitation of natural resources, a study based on the automatic analysis of LANDSAT data was undertaken (Santos et al., 1980). The study defined in two distinct seasons the best channel or combinations of channels for the discrimination of different Cerrado vegetation forms.

The study area is located on the "Planalto Central", in the Federal District (DF) - Brasília. Occupying an area of 5,750 km², the DF is situated between the coordinates south latitude 15° 00' to 16° 30' and west longitude 47° 00' to 48° 30' (Figure II.4). This area was selected for its geo-economic importance in the Cerrado region and principally owing to its localization in the core of the vegetation dominion.

The study utilized the classifications of Cerrado forms adopted by Foodland (1969), Ferri (1975) and Aoki and Santos (1979) as follows: cerradão, cerrado, campo cerrado and campo sujo de cerrado. For this study, cerradão forms, nearly absent in the Federal District, were excluded.

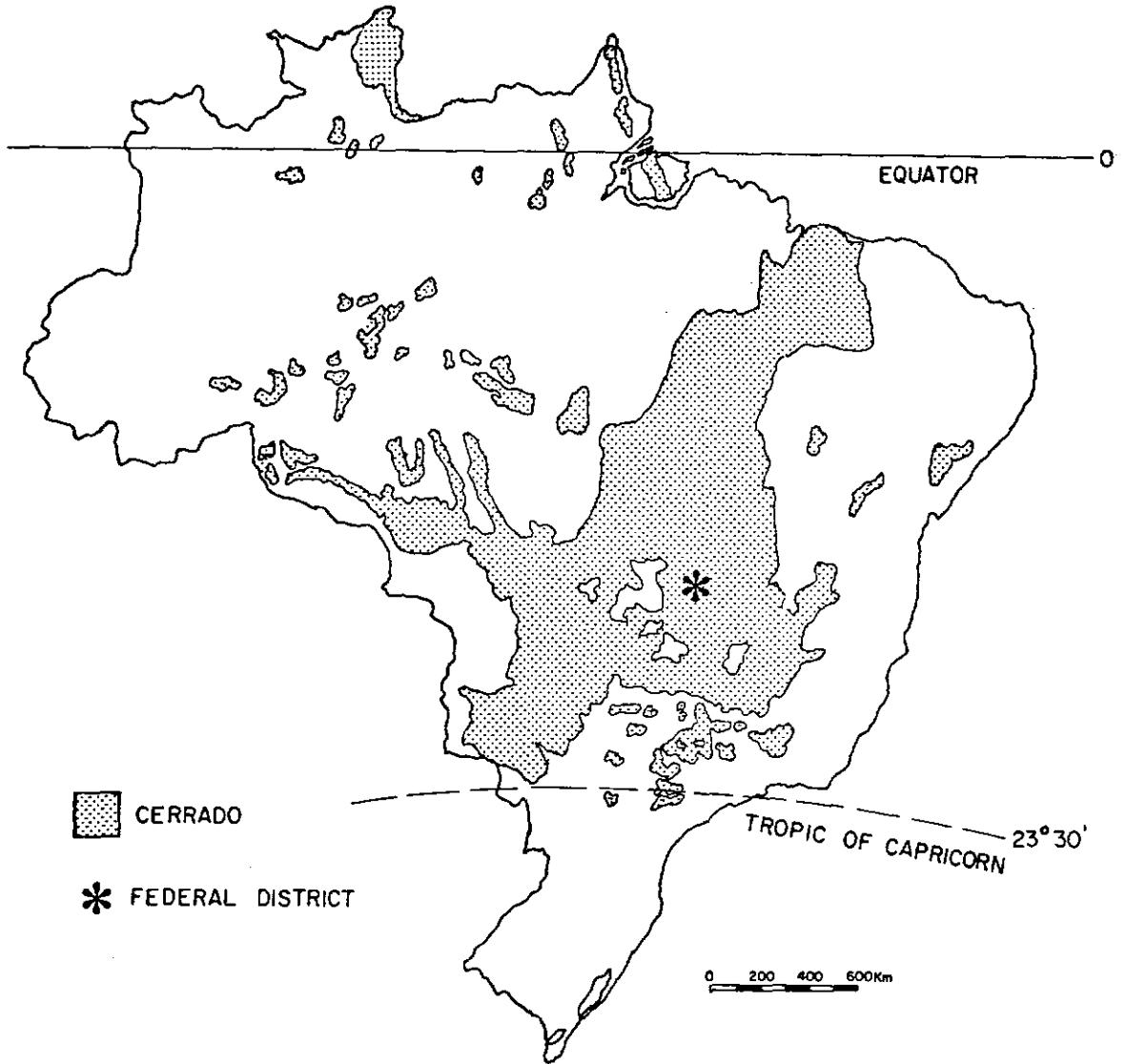


Fig. II.4 - Location of the study area.

LANDSAT CCT's in four channels and black and white photographic imagery at the 1:250,000 scale were used. As the Cerrado vegetation elicits a distinct spectral behavior throughout the year, imagery were chosen relative to the passage date 02.08.1977 and 08.07.1977, corresponding the rainy and dry season.

The interpretation of the CCT's data was executed by the IMAGE-100 system. Adopting the analytical sequence cited by Anuta et al. (1971), the handling of CCT's was as follows; 1) pre-processing, 2) training area selection and spectral signature analysis, and 3) automatic classification and evaluation of results.

The training area selection was initially based on visual interpretation of imagery (1:250,000) and field check. A "maximum likelihood" algorithm (MAXVER), developed by Velasco et al. (1978), was used to extract the spectral signatures of each Cerrado form. Also JM distances (Jeffrey Matusita Distances) were obtained, whose values were correlated to values of "probability of correct classification" (Swain and King, 1973) to verify class separability (Figure II.5). Based on these values, the best channels or combination of channels were established to discriminate Cerrado forms in the time period analyzed.

The spectral values of Cerrado forms obtained by "maximum likelihood" classification are presented in Table II.1 and Figure II.6. Observe that Cerrado forms elicit a gradient of tonality, confirming the presence of an ascending biomass gradient from "campo sujo" to "cerrado". This fact permitted the separation of Cerrado forms.

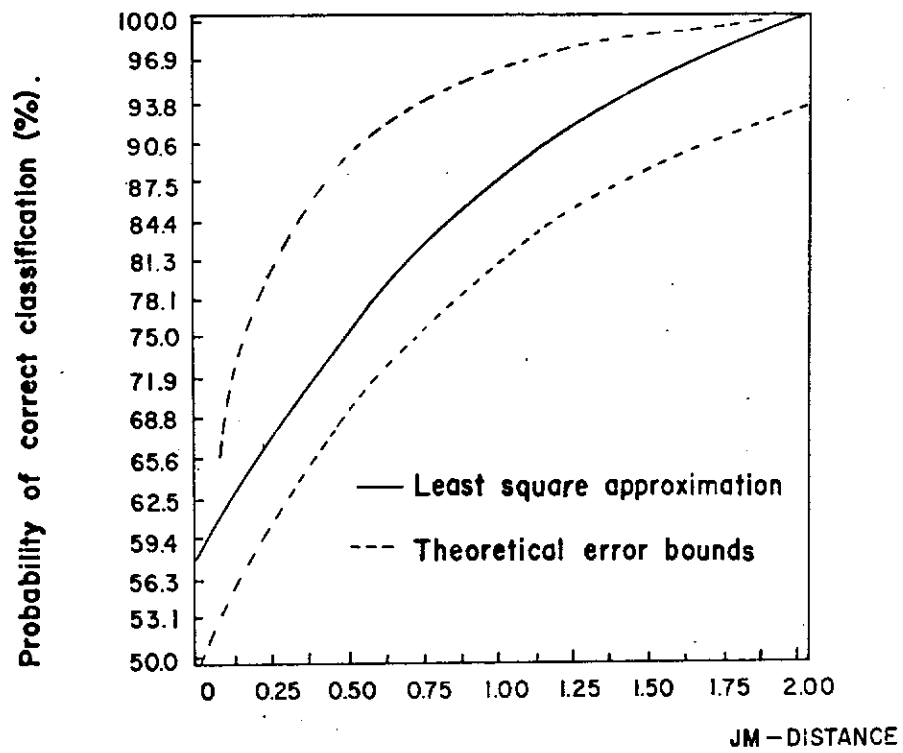
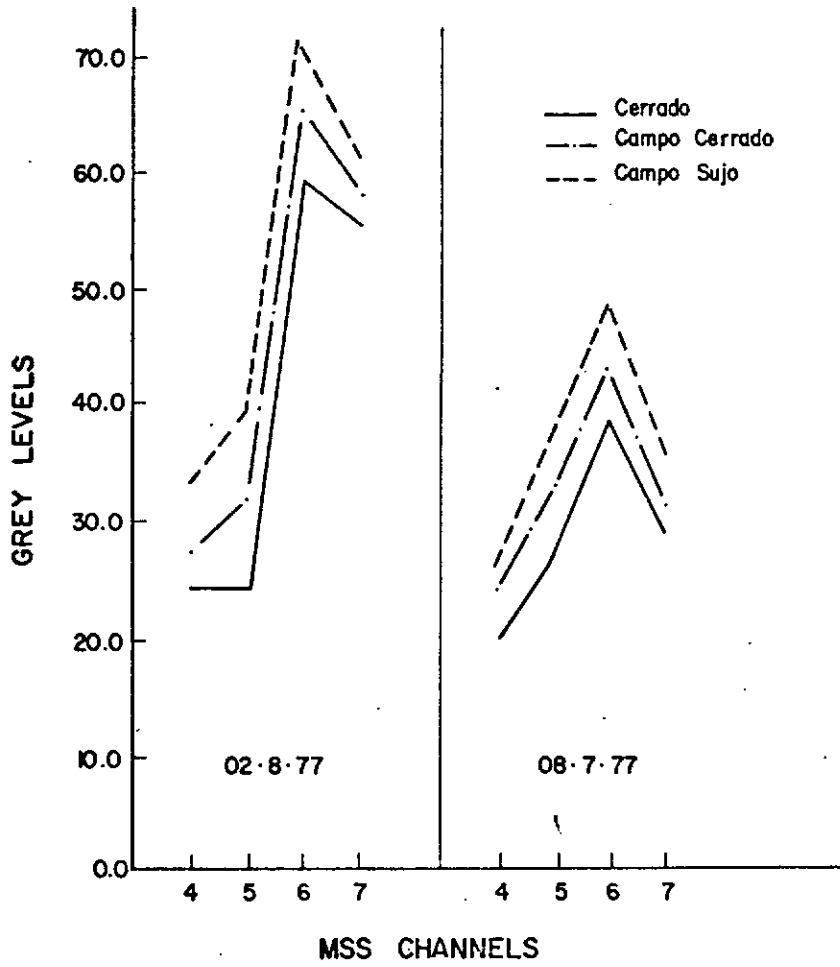


Fig. II.5 - Graph of probability of correct classification of JM distances.

From: Swain and King (1973)



Spectral behavior of Cerrado forms in four channels (wet/dry season)

Fig. II.6 - Spectral behavior of Cerrado forms in four channels.
(wet/dry season)

The graphs (Figure II.6) further show that Cerrado forms present highest electromagnetic radiation absorption in the range 0.5 μm to 0.70 μm (channels 4 and 5). Conversely, they present high reflectance and low absorption in the range 0.70 μm to 1.1 μm (channels 6 and 7). In addition, reflectance values in the rainy season scene (02.08.77) are higher than those of the dry season (08.07.77) because of vegetation exuberance.

The values for "between class" JM distances applied to a graph of "probability of correct classification" (Figure II.5) are presented in Table II.2.

It was verified that the combination of four channels present a higher performance (around 96.0%) in the discrimination of the three classes analysed.

It was also observed that the "cerrado" form compared to "campo sujo" was better discriminated in the rainy season (02.08.77), independent of the number of channels employed. The dry season (08.07.77) provided the best condition of separability for the "campo cerrado" forms.

With relation to the combination of three channels, the data set furnished by channels 4, 5 and 6 were shown to be more precise to discriminate the Cerrado forms, independently of the time of the season. With respect to the combination of two channels, also independently of the season, a channel 5 and 6 combination was found to be better to separate "cerrado" from "campo cerrado", while "campo sujo" was better distinguished from the other two forms in the channel 4 and 5 combination.

TABLE II.1

SPECTRAL PARAMETERS OF CERRADO FORMS,
OBTAINED FROM THE MAXVER PROGRAM

MSS CHANNELS FORMS	DATES							
	RAINY SEASON (02.08.1977)				DRY SEASON (08.07.1977)			
	4	5	6	7	4	5	6	7
"cerrado"	24.56	24.61	59.28	55.28	19.68	26.07	38.45	29.74
"campo cerrado"	27.77	32.03	65.24	57.89	21.42	31.70	42.24	31.51
"campo sujo"	32.97	39.41	71.89	62.24	25.44	38.29	47.56	35.47

TABLE II.2

INDICES OF CORRECT CLASSIFICATION BETWEEN CERRADO FORMS OBTAINED FROM
CHANNEL OR CHANNEL COMBINATION OF ANALYSIS

DISCRIMINATION BETWEEN FORMS* COMBINED	DATES						
	RAINY SEASON (02.07.1977)			DRY SEASON (08.07.1977)			
	Ce Cc	Ce Cs	Cc Cs	Ce Cc	Ce Cs	Cc Cs	
4 Channels	94.40	99.80	95.20	95.30	99.60	96.00	
3 Channels	93.95	99.80	95.00	95.10	99.50	95.70	
2 Channels	93.35	99.80	93.50	95.10	99.40	94.77	
1 Channels	90.65	99.50	88.25	91.00	99.00	89.50	

* Ce - "cerrado"; Cc - "campo cerrado", Cs - "campo sujo".

The results of the analysis of separate channels are presented in Table II.3. Note that channel 5 exhibits a better discrimination of Cerrado forms, independently of the season analysed.

The discrimination of different physiognomic unities of Cerrado vegetation can be extremely useful for the identification of areas most suitable for multiple land uses, including agriculture, pasture and silviculture. Cerrado vegetation is associated with certain soil types. Within the three forms studied, "cerrado" is generally distributed in soils of high quality.

Presently, the methodology is being applied to map the whole Cerrado region (Figure II.4).

2.4.3 - ARTIFICIAL FOREST APPLICATIONS

Reforestation studies using remote sensing techniques in Brazil began in 1976 in the Ribeirão Preto Agricultural Administration Division (DIRA) of São Paulo State (Figure II.7). A study area with approximately 35,000 km² and predominantly occupied by *Pinus* and *Eucalyptus* plantations was chosen.

Eight training areas were selected to represent the various existing age and species groups. Through visual and computer-aided analysis four reforestation classes were derived: *Pinus elliottii* (PE), *Pinus taeda* (PT), *Eucalyptus* from eight months to two years old (E1) and *Eucalyptus* over two years (E2). Table II.4 shows the results of visual interpretation for *Pinus* and *Eucalyptus*. Accuracy in visual interpretation was 87.79% for *Pinus* and 94.80% for *Eucalyptus*.

Computer-aided analysis (IMAGE-100) results for another training area (Mogi-Guaçu) of 45,800 km² are presented in Table II.5.

TABLE II.3

JM DISTANCES VALUES BETWEEN "CERRADO" FORMS OBTAINED FROM WET/DRY
SEASON ANALYSIS OF SEPARATE MSS CHANNELS

DISCRIMINATION BETWEEN FORMS	CHANNELS	02.08.1977		08.07.1977	
		JM	PERFORMANCE (%)	JM	PERFORMANCE (%)
"CERRADO/ CAMPO CERRADO"	4	0.74	81.00	0.42	72.60
	5	1.21	90.65	1.23	91.00
	6	0.77	81.75	0.74	81.00
	7	0.34	67.00	0.34	70.00
"CERRADO/ CAMPO SUJO"	4	1.61	96.10	1.48	94.70
	5	1.95	99.50	1.90	99.00
	6	1.46	94.40	1.46	94.40
	7	0.90	85.00	1.01	87.65
"CAMPO CERRADO/ CAMPO SUJO"	4	0.91	85.25	1.01	87.65
	5	1.05	88.25	1.13	89.50
	6	0.67	79.25	0.88	84.50
	7	0.50	75.00	0.58	77.00

* Probability of correct classification.

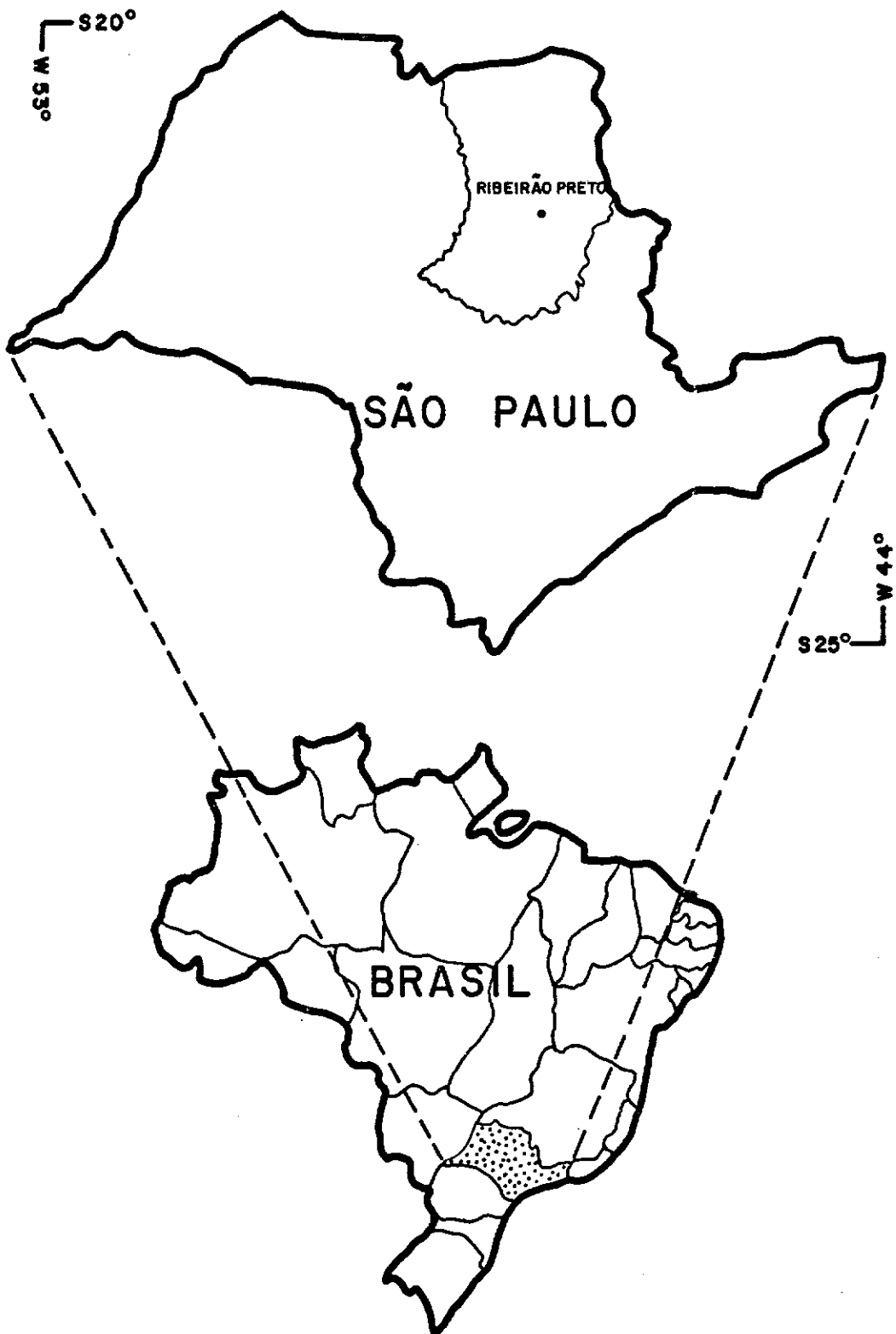


Fig. II.7 - Location map of the study region.

TABLE II.4

PINUS AND EUCALYPTUS CLASSIFICATION
(Ribeirão Preto Dira)

CLASSES	AREA (Ha)	PERCENTAGE
Eucalyptus	56,810.12	1.60
Pinus	3.159.38	0,09
Others	3,489,864.93	98.31
TOTAL	3,549,834.43	100.00

TABLE II.5

PINUS AND EUCALYPTUS CLASSIFICATION
(Mogi-Guaçu Region)

CLASSES	AREA (Ha)	PERCENTAGE
PE	2,055.20	4,49
PT	155.00	0.34
E1	466.60	1.02
E2	4.749.40	10.38
OTHERS	38,329.10	83.77
TOTAL	45,755.30	100.00

The methodology developed in the previous applications was then utilized in the state of Mato Grosso do Sul (Figure II.8). The studied area is located between the cities of Campo Grande and Tres Lagoas and corresponds to an extension of about 300,000 km². Information about farms with reforestation was obtained from IBGE (Brazilian Institute for Geography and Statistics) maps. Six preliminary classes were defined according to their species and age groups (Table II.6).

TABLE II.6

PINUS AND EUCALYPTUS CLASSIFICATION: PRELIMINARY CLASSES
(State of Mato Grosso do Sul)

CLASSES	AGE	CONDITION
Assigned Reforested Area	Eucalyptus < 4 Months Pinus < 2 Years	—
E1	8 Months < Eucalyptus < 1 Year and 2 Months	—
E2	1 Year and 2 Months < Eucalyptus < 3 Years	homogenous
E3	1 Year and 2 Months < Eucalyptus < 3 Years	heterogeneous
E4	Eucalyptus > 3 Years	—
PINUS	> 2 Years	—

Due to the low LAI (leaf-area index), *Pinus* plantations with an age less than two years and *Eucalyptus* with less than four months were mapped as bare soil. After this initial classification three classes of reforestation were defined (Table II.7).

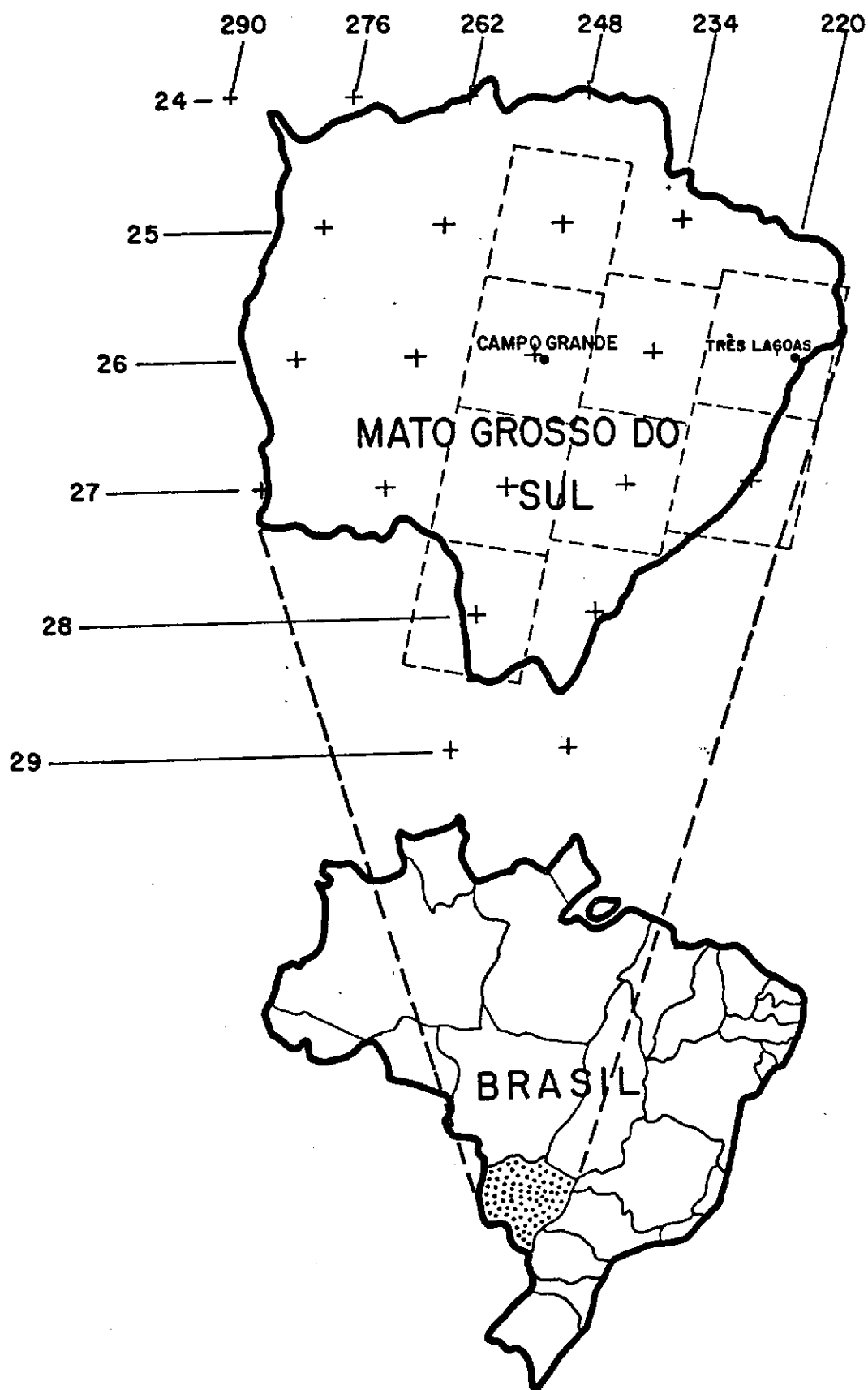


Fig. II.8 - Location map of the study region.

TABLE II.7

PINUS AND EUCALYPTUS CLASSIFICATION: FINAL CLASSES
(State of Mato Grosso do Sul)

CLASSES	AGE
Assigned Reforested Area	Eucalyptus < 4 Months Pinus < 2 Years
Eucalyptus	Eucalyptus > 4 Months
Pinus	Pinus > 2 Years

The comparison between visual estimates and ground information is shown in Table II.8.

TABLE II.8

PINUS AND EUCALYPTUS CLASSIFICATION: COMPARISON
BETWEEN VISUAL ESTIMATES AND GROUND INFORMATION
(State of Mato Grosso do Sul)

CLASSES	GROUND INFORMATION (Ha)	VISUAL ESTIMATES (Ha)	RELATIVE DIFFERENCES (%)
Assigned Reforested Area	49,192.17	48,827.50	- 0.74
Pinus	222,594.07	229,532.00	3.11
Eucalyptus	12,815.36	13,593.00	6.06
TOTAL	236,601.60	291,952.50	2.58

Computer-aided interpretation using the IMAGE-100 system was then carried out in several test areas. One of these test area was Itapeva. Based on field information and visual interpretation of LANDSAT imagery, the following classes were identified:

- 1) Eucalyptus - plantation with 100 % coverage
- 2) Young Eucalyptus - young plantation with partially exposed soil
- 3) soil in preparation for plantation
- 4) bare soil - deforested area
- 5) Cerrado - area with natural vegetation
- 6) Other classes

The estimated areas for these six classes are shown in Table II.9.

TABLE II.9
PINUS AND EUCALYPTUS CLASSIFICATION: ESTIMATE AREAS
(Itapeva District)

CLASSES	AREA	
	Ha	%
Eucalyptus	18,319.40	17.36
Young Eucalyptus	6,613.50	6.27
Soil in preparation	8,084.60	7.66
Bare soil	26,862.60	25.42
Cerrado	44,604.00	42.26
Other classes	1,091.80	1.03
T O T A L	105,539.90	100.00

It is not necessary to discuss here the important aspects related to reforestation and its well known applications. However, it is worthwhile to mention that the Brazilian Government has recently offered several fiscal incentives to encourage reforestation with the main objective of obtaining alcohol from the distillation of wood. The substitution of gasoline by alcohol will reduce the dependence on imported petroleum and thus relieve the country energy crisis.

The conventional energy resources either hydroelectric or fossil have limited reserves. Nevertheless, the use of artificial reforestation as an alternative energy source has several advantages for Brazil, as reforested trees need a short period of time to reach cutting age, are renewable, cause less problem to environment, and may solve social problems by offering more employments.

CHAPTER III

APPLICATION TO THE BRAZILIAN AMAZON REGION

3.1 - CHARACTERIZATION

Regions covered by tropical rainforest in the world are characterized by a low index of human activity and the Amazon region is a typical example.

The Amazon Forest is the largest tropical rainforest of the world and occupies approximately 30% of the Brazilian territory (Pandolfo, 1978) and considerable part of the Guianas, Suriname, Venezuela, Colombia, Pery, Equador and Bolivia. Due to the low population and highway densities and the low number of towns, the Brazilian Government has encouraged its occupation.

As the other existing large tropical rainforest little information exist about the Brazilian Amazon forest which difficult the planning for its explotation. In 1970, a first project was carried out using radar imagery to study the Amazon Forest (later, it became the RADAMBRASIL Project) and the first results were available in the beginning of 1973. However, the single data acquisition provided by the project has limited the possibility of studying the process of human occupation in that area.

For several years the problem of deforestation in the Amazon Forest had raised considerable national and international interest. Nevertheless, to study it by conventional methods would be unpractical due to the extensive area (Brazilian Amazon region encompasses an area of approximately 4,900,000 Km²) and to the dynamic features of the deforestation processes.

LANDSAT system, whose data are received by INPE since 1972, meets the requirement of providing multi-temporal data (every 18 days) with relatively low cost. It is the most suitable technique to study the process of human activity in remote and large areas such as the Brazilian Amazon region.

3.2 - MAPPING THE BRAZILIAN AMAZON FOREST

In order to utilize the natural resources of a certain area, information about its vegetation coverage has to be obtained. In a large area such as the Amazon region, with difficult access, remote sensing techniques using satellite data (LANDSAT) are an indispensable tool for survey purposes.

Studies in Amazon region using LANDSAT data were reported by Pinto et al. (1979) and Santos et al. (1981) and the results can be summarized as follows:

1. A joint-project with the Brazilian Institute for Forestry Development (IBDF) was developed to verify the potentiality of using LANDSAT data for a natural resource inventory in the National Park of Amazon - Tapajós (Figure III.1). This park is located in the middle course of the Tapajos River and encompasses a part of Para and Amazon States, with an area of about 10,000 km² delimited by coordinates 3°50' ~ 5°00'S and 56°16' ~ 57°30' W (IBDF, 1978).

The Tranzamazon road passes through the southwestern part of it.



Fig. III.1 - Location map of the study area.

LANDSAT imagery with path/row annotation 304/14, channel 5 and 7, scales of 1:500,000 and 1:250,000 were used in this study. The analysis procedure included: preliminary visual interpretation to delineate different mapping units; field trips to verify mapping accuracy; correction of preliminary mapping units and establishment of final legend (Pinto et al., 1979).

Tonality patterns were used to discriminate different vegetation units. The areas with the same spectral response that is, the same tonality pattern, were grouped into the same class.

Four vegetation classes were found:

- dense forest: this class occupies a large part of the park and is characterized by an uniform coverage, where deciduous and everygreen forest are found;
- open forest-group I: this class is characterized by an heterogeneous vegetation coverage. It is predominantly constituted by everygreen trees but sparsely distributed high tree species caused the imagery to be mottled.
- open forest-group II: the same as group I, except that the trees belong predominantly to the deciduous and everygreen species and are not as high as in group I.
- alluvial forest: this class is formed along the riverside and the Tapajos island and everygreen species are predominant with an average height lower than those presented in the non-alluvial area.

The results presented above show that definitely LANDSAT imagery can be used for delimitation and identification of vegetation. The resulting information, together with geological and geomorfological data, permit and adequate planning and management of the natural resources principally for protection and conservation purposes.

The methodology developed is now being applied by INPE and IBDF to other National Parks.

2. Project Amazon, which was carried out by participants of several governmental organizations of the Amazonas State, under the technical coordination of INPE in an area of approximately 35,000 km², located from 58°30' to 61°30' and from 2°30' to 4°00'S (Figure III.2). It was selected due to its importance for the agricultural and pastureland project development in the region and was covered by 3 LANDSAT images paths 332, 346 and 360 and rows 14 and 15.

Black and white LANDSAT imagery of channel 5 and 7, at the scale of 1:250,000 and 1:500,000 were used in the study. The RBV imagery of 332/141 sub-scene C was also utilized in order to evaluate qualitatively the vegetation and the area occupied.

For visual interpretation of MSS LANDSAT imagery, the following procedures were employed:

- marking the coordinates
- trace of the drainage
- delimitation of cities, villages and highways
- identification of vegetation units and deforested areas.

The detailed description of the methodology can be found in the report by Santos et al. (1981).

Interpretation results show that vegetation and deforested area can be mapped in MSS imagery using tonality and texture patterns. However, for interpretation of RBV imagery, tonality was the only pattern used.

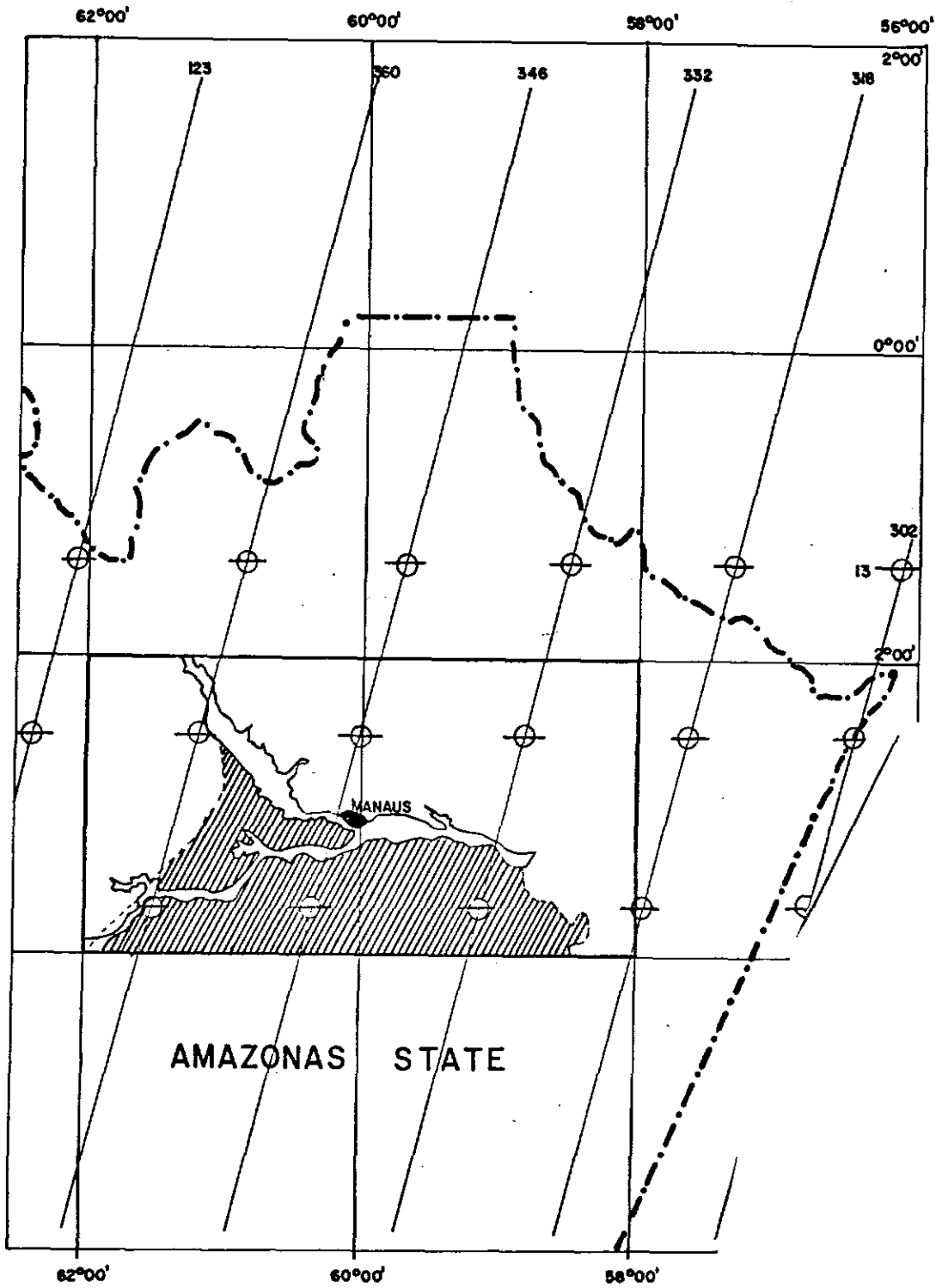


Fig. III.2 - Location map of the study area

The following vegetation units were derived from MSS imagery and ground truth information: mixture of forest-grassland, sparse forest on land liable to inundation, open tropical forest with Brazilian Palm, dense tropical forest (with or without Brazilian Palm) and forest of secondary growth. Also deforested areas for pasture in alluvial and upland were mapped.

The vegetation classes which were discriminated from RBV imagery were: open alluvial forest of terrace or flood plain, dense forest and clear area.

It was also concluded that LANDSAT channel 5 (visible) and 7 (infrared) imagery provided better vegetation information than the RBV imagery. This is explained by the spectrum region detected by the RBV system (505 ~ 750 nm which corresponds to visible radiation). However, deforested areas were more precisely mapped with RBV imagery, due to its higher resolution. The obtained information are of great importance for forest inventory and management of pastureland projects implantation.

Presently, a vegetation mapping using LANDSAT data is under way for the whole Amazon region.

3.3 - DEFORESTATION IN THE BRAZILIAN AMAZON FOREST

Since the end of the 60 decade, Brazilian Government was worried about the occupation of the Amazon region and its economical integration with the rest of the country. As the Amazon is the only existing tropical forest not yet drastically altered by man and because of its localization far from the large urban centers, the occupation strategy to be adopted for the region should definitely consider the preservation of the environment.

As a consequence of a federal program on fiscal incentive distribution, the pasture activity in the Amazon region rapidly increased after 1969. SUDAM (Brazilian Government Superintendence for the Amazon Development), the federal agency in charge of the distribution of these incentives had no efficient ways to control these enterprises.

With the construction of a great number of highways crossing the Amazon region (for example, the Belém/Brasília, Transamazônica, Cuiabá/Santarém, Cuiabá/Porto Velho highways) persons and companies were attracted to occupy that region, either using economic incentives or proper resources.

As a consequence of the implantation of the pasture projects, some problems appeared. Among them one can mention the localization of the project, lease-holder, land regulation, incorrect limits etc.:

But the launching in 1972 of the first LANDSAT satellite changed the whole situation. Due to its repetitive and synoptic characters and presenting the possibility of obtaining low cost data when compared to conventional methods, it became the natural choice to control and monitor the Amazon deforested areas.

In 1975, an Agreement between SUDAM and INPE was signed with the objective to develop and implement a methodology for the utilization of LANDSAT data in the control and monitoring of the Legal Amazon deforestation (Santos and Novo, 1977). A pilot project was defined for an area of approximately 150,000 km² (Figure III.3) in the northeastern part of Mato Grosso State (municipal districts of Barra do Garças and Luciana), where at that time a rapid process of deforestation for implantation of pasture projects was under way.

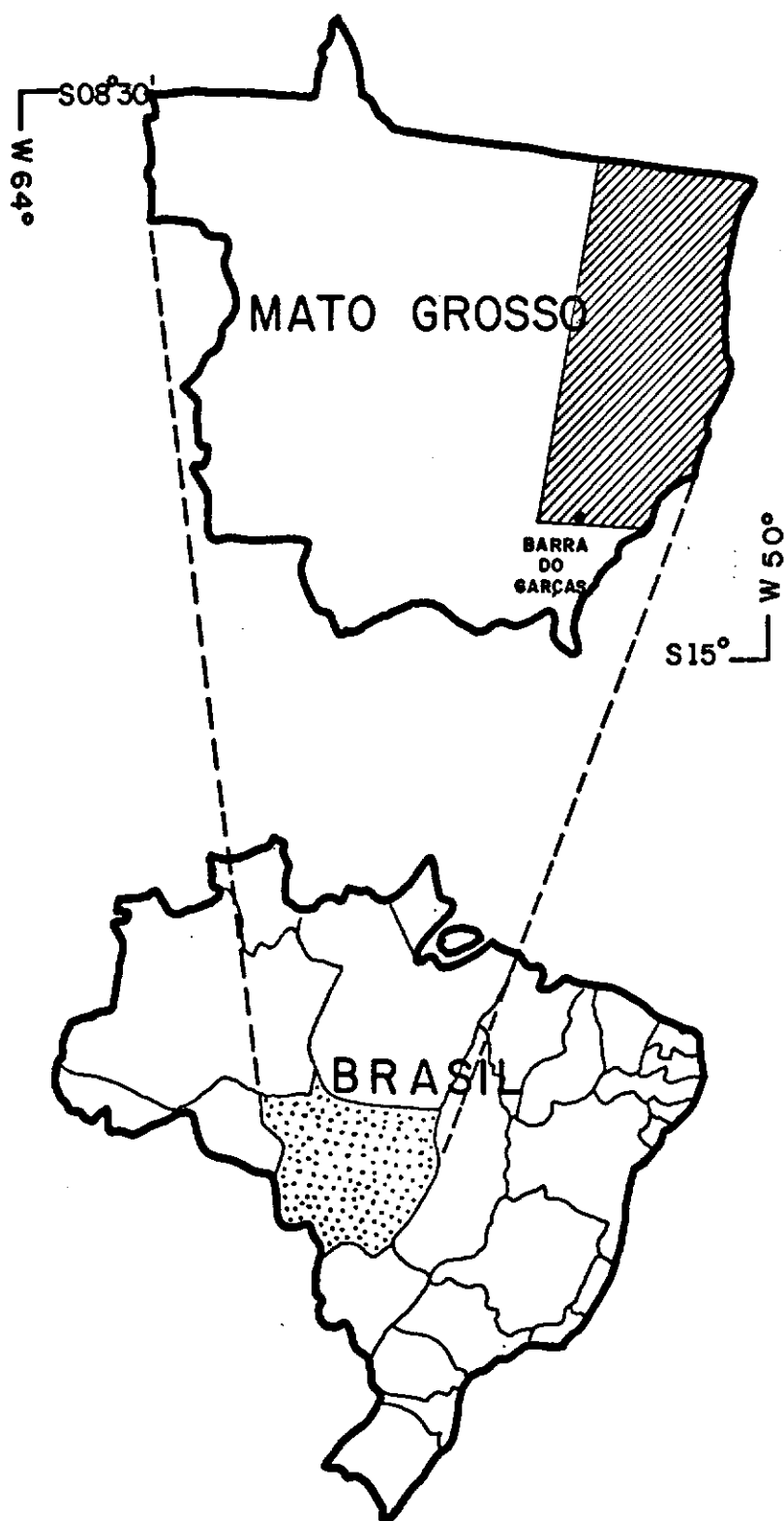


Fig. III.3 - Location map of the study region.

Black and white channel 5 and 7 LANDSAT images obtained in August 1976 (scale 1:250,000) were used. Mapping of the deforested areas was done through visual analysis of tonality and texture.

The methodology developed consisted of delimitation of the deforested areas on the images; field work and determination of the area limits; correction of these limits and estimation of the area. The boundaries of the projects were determined with the help of the maps provided by the owners and descriptions based on geographic accidents. The deforested area was interpreted by visual analysis in channel 5 and 7 images and the computation of its surface was obtained using an one millimeter dot grid (Santos and Novo, 1977).

The total deforested area found was 700,339 hectares. From this total, 289,840 hectares corresponded to pasture projects that received economic incentives from SUDAM. It was also showed that 59% of the deforestation occurred in the forest, 29% in the savanna and 12% in the "cerradão".

Evaluation of the quality of the cultivated pastures was also done, because it could be considered as an indicator of the soil management conditions. The average percentage of deforested areas having pastures with high potential utilization was 55.07% . Therefore, it was possible to infer that 45% of the studied deforested areas were sub-utilized . The results also showed that in 90% of the cases the average was varying from 50% to 60%, indicating low levels utilization of the deforested areas in the region.

Based on the results obtained in that work, it was possible to conclude that LANDSAT orbital data analysis allowed for the development of operational deforestation vigilance programs for the Legal Amazon.

In 1978, a great controversy was created about the amount of deforested area in the Amazon region. Then, in order to clarify the situation, a new agreement was established between IBDF (Brazilian Institute for Forest Development) and INPE, with the objective to verify to what extent (percentage) the Legal Amazon was deforested.

Initially, a pilot project was performed in the Federal Territory of Rondônia, in an approximate area of 100,000 km². The methodology used was the same proposed by Santos and Novo (1977), and the work was done with LANDSAT images of August 1977.

The deforested area was found to be equal to 286,339 hectares, corresponding to 2.8% of the total area. Although apparently insignificant, it was a result of deforestation that occurred in the last 5 years of land occupation!

A new agreement was then established between INPE and IBDF, expanding the project to cover the whole Legal Amazon region. Besides the calculation of the Amazon deforestation, the program included a complete transference of the technology developed to the IBDF researchers.

The methodology used was the same proposed by Santos and Novo (1977), but the deforestation was calculated for two periods: 1973/1975 and 1976/1978. LANDSAT images at the scale 1:500,000, channels 5 and 7, were used (total of 1,244 images).

The results showed that during the period 1976/1978 the whole Legal Amazon deforestation reached a total of 7,717,175 hectares. As the Legal Amazon region has 497,552,700 hectares, then the total deforested area corresponds to 1.55%. Table III.1 presents the results obtained for both periods.

TABLE III.1
DEFORESTED AREA IN LEGAL AMAZON

STATE OR FEDERAL TERRITORY	AREA EXTENT (ha)	DEFORESTED AREA (ha)		INCREMENT (%) $\left(\frac{B - A}{A}\right) \times 100$	% DEFORESTATION OF THE STATE OR FEDERAL TERRITORY
		1975 (A)	1976/1978 (B)		
FEDERAL TERRITORY OF AMAPÁ	13,906,800	15,250	17,050	11.80	0.122
PARÁ STATE	122,753,000	865,400	2,244,525	159.36	1.828
FEDERAL TERRITORY OF RORAIMA	24,300,400	5,500	14,375	161.36	0.059
MARANHÃO STATE (*)	25,745,100	294,075	733,400	149.39	2.848
GOIÁS STATE (*)	28,579,300	350,725	1,028,850	193.35	3.600
ACRE STATE	15,258,900	116,550	246,450	111.45	1.615
FEDERAL TERRITORY OF RONDONIA	23,010,400	121,650	418,450	243.98	1.818
MATO GROSSO STATE	88,100,100	1,012,425	2,825,500	180.07	3.218
AMAZONAS STATE	155,898,700	77,950	178,575	129.08	0.114
LEGAL AMAZON	497,552,700	2,859,525	7,717,175	169.88	1.551

(*) The area of the State is not totally included in the Legal Amazon.

Although the deforestation percentage (1.55%) can be considered low, the deforestation increment rate cannot (169.88% in the last 3 years).

The Mato Grosso State presented the largest deforested area (2,825,500 hectares), followed by the States of Pará (2,244,525 hectares) and Goiás (1,028, 850 hectares). As far as the deforestation increment rate is concerned, the Federal Territory of Rondônia revealed the highest value (243.98%), followed by the States of Goiás (193.35%) and Mato Grosso (180.07%).

Figure III.4 shows the critical deforestation areas in the Legal Amazon. It could be observed that there are four major critical areas: the first localized in the State of Mato Grosso; the second in the Federal Territory of Rondônia (transition area between open forest and "cerradrão"); the third along the Belém/Brasília road (Araguaia - Tocantins) and the fourth situated in area of dense forest in the triangle Belém-Altamira-Santarém. A special surveillance program for the critical areas is now under way.

It is also interesting to observe that LANDSAT D, with 30 meters resolution and a greater number of channels, will allow for better identification of the small deforested areas, thus producing more accurate evaluations.

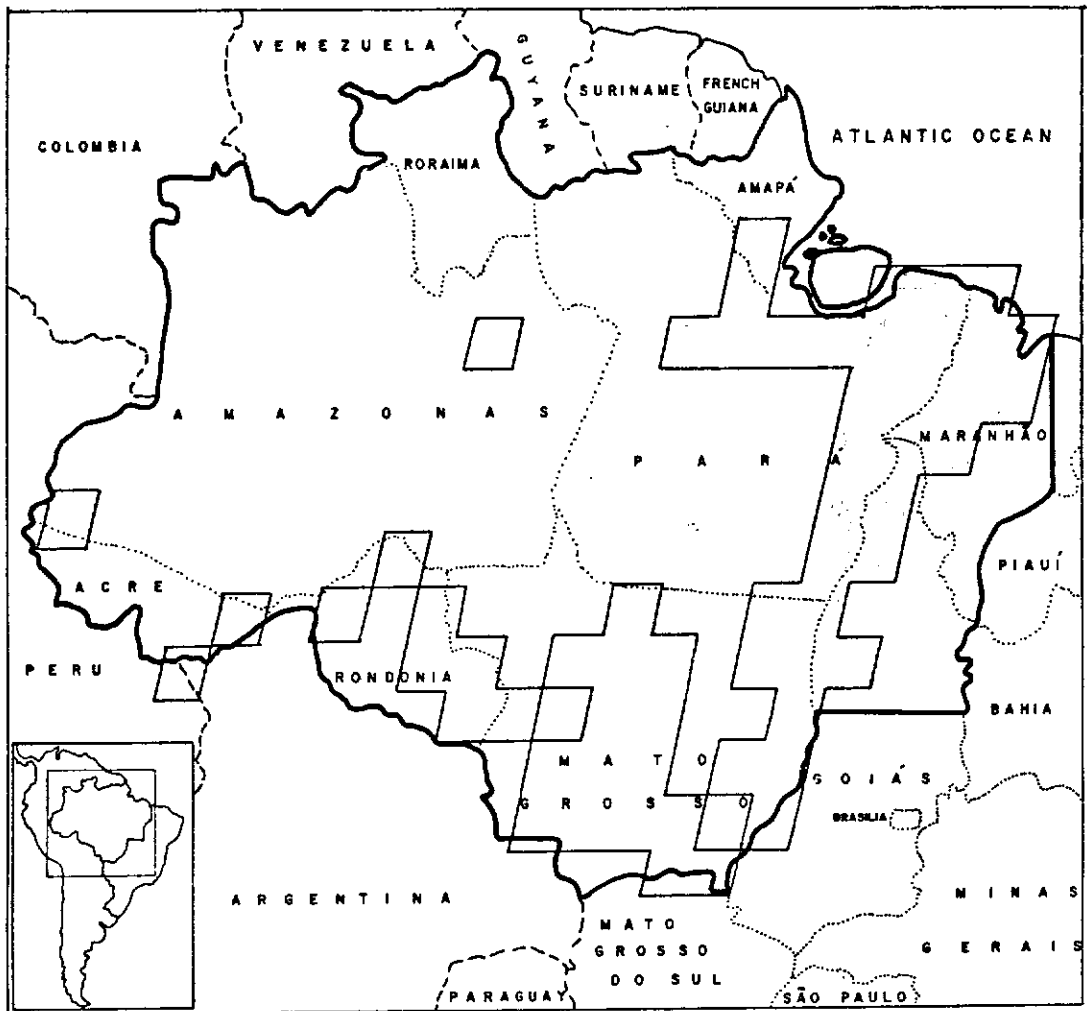


Fig. III.4 - Location map of legal Amazon showing the concentrated deforestation areas.

3.4 - EVALUATION OF PASTURE DEGRADATION AFTER DEFORESTATION

The utilization of LANDSAT data to study the impact of the implantation of pasture projects in the Amazon region, was first envisioned when the deforestation monitoring and control program described in last paragraph was been developed.

The objective of the research was to verify if LANDSAT images could provide useful data for the evaluation of pastureland degradation after deforestation. The relationship between pastureland quality and occupation time and between topomorphologic units and pasture quality, and the definition of the pasture elements that would be used as indicators of their degradation were the principal questions analised in the study.

The Paragominas municipality (Figure III.5) was chosen as pilot area because it is one of the oldest region of pasture occupation in tropical forest region.

Black and white LANDSAT images, channels 5 and 7, were used at the scales of 1:500,000 and 1:250,000. Also CCT's tapes corresponding to the same images were used.

The developed methodology was based on visual interpretation of LANDSAT images. A map with the deforested area distribution and an outline of the principal topomorphologic units was obtained. Automatic interpretation was utilized to classify the pastureland. Two field works were done in the dry and rainy seasons in order to collect information for establishing a relationship between the pastureland quality and the spectral response. Also, research was carried out in order to establish a pasture typology relating the degradation condition to the deforestation time.

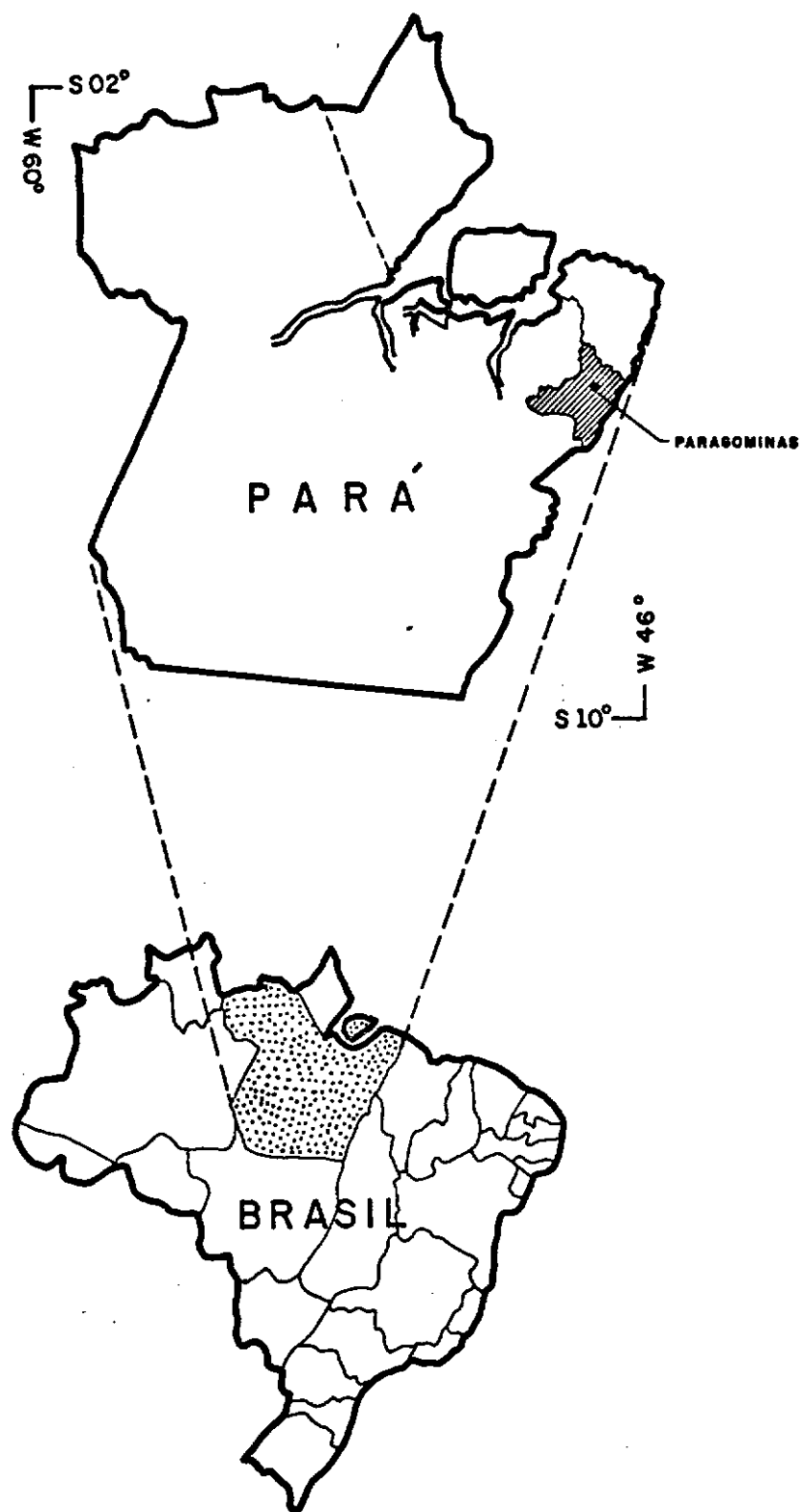


Fig. III.5 - Paragominas Municipality in the Para State.

Initially, a relationship between the time after deforestation and the pasture quality was searched. The hypothesis was that the soils under forest once occupied by artificial pastures would decrease their fertility, causing the reduction of pasture quality.

Soil samples were collected taking into account the occupation time, topography and management of pastures. The determination of a soil degradation indicator, which could be evaluated through remote sensing techniques, was one of the goals of the work. Thus, the percentage cover by "juquira" (natural vegetation regrowth) and the percentage of soil exposure were considered to be related to pastureland conditions, which could be related to the chemical properties of the soils.

The pastures observed in the field were divided into five categories: excellent (100% of grass and/or legume species coverage); good (from 70% to 90% of grass and/or legume species coverage); fair (from 50% to 70% of grass and/or legume species coverage and the rest of other coverage distributed into "juquira" and exposed soil); poor (from 10% to 50% grass and/or legume species coverage) and very poor (from 10% to 50% of grass and/or legume species coverage and the rest of exposed soil).

Figure III.6 shows the results of the soil samples analysis. In the initial phase (soils under forest) it was observed a low level of fertility, with a 5% of organic matter, cation saturation of 18%, pH (4,4) and cation exchange capacity of 10 mE.

In the second phase (1 to 4 years after deforestation) it could be observed an accentuated change in the analysed parameters. The pH increased to 5,2 and the percentage of cation saturation doubled. The pH and cation saturation increasing can be related to the burning effects which release mineral nutrients from the plant tissues.

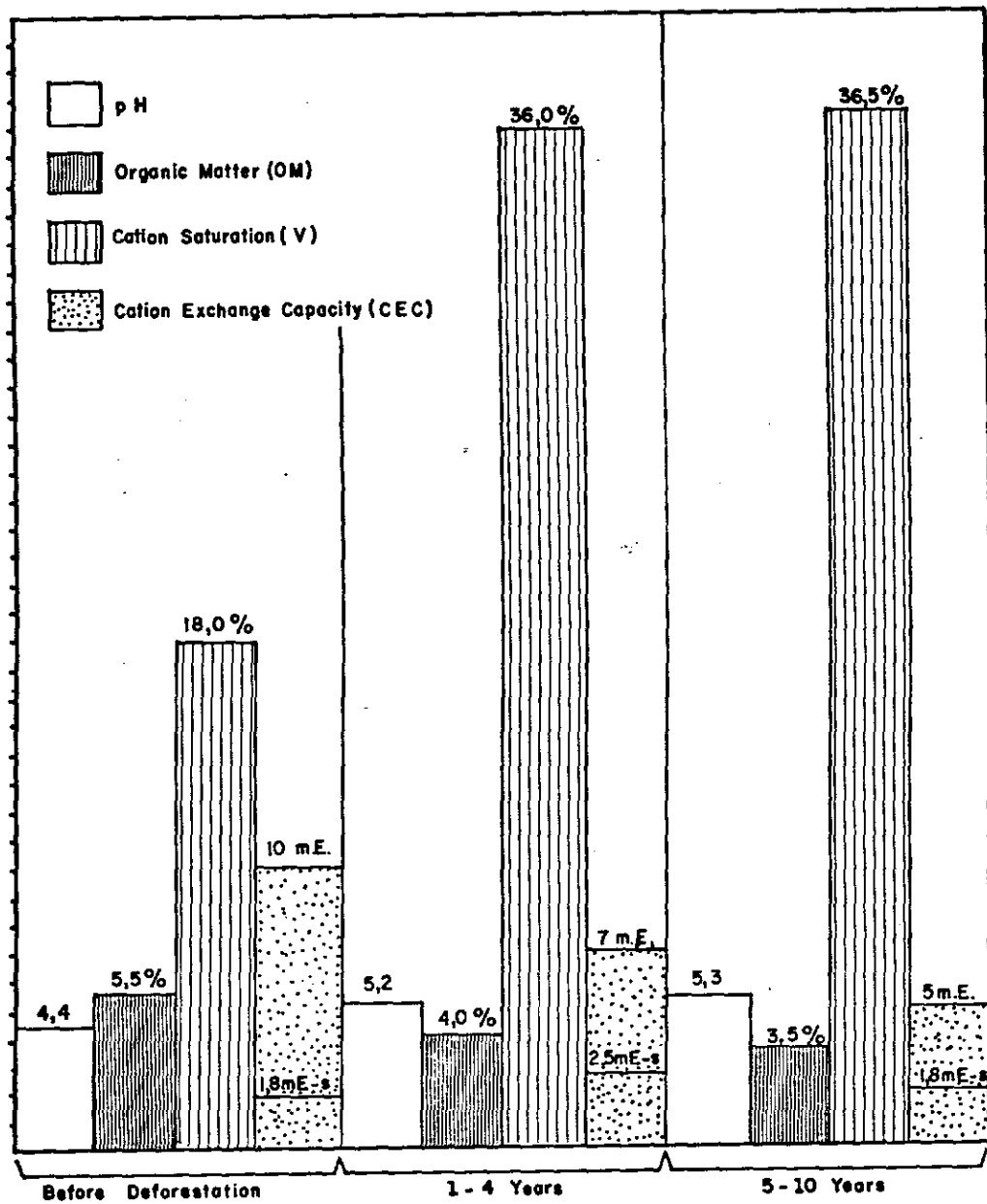


Fig. III.6 - Soil samples analysis.

The 10% reduction in the organic matter content represents a lost of approximately 10 ton of organic matter/ha, for a soil depth of 10 cm and density equal to one.

The behavior of other physical-chemical properties can depend on the soil organic matter content. For instance, the organic matter has an important influence in the moisture retention at the soil surface, which is responsible for the normal germination of the seeds. In two soils with different organic matter content (2.2% and 4.2%) the grass germination was different - there was no germination where the organic matter content was lower. It is important to observe that other factors as topography and the presence of lateritic soil can affect the organic matter content and consequently the pastureland quality.

In the third phase (5 to 10 years after deforestation) it was observed that the organic matter content decreased to 3.5% and the absolute value of the cation saturation percentage presented no alteration (36.5%).

The pasture quality versus occupation time diagram is shown in Figure III.7. It can be observed that up to 5 years of occupation, 70% of the analysed pastures are classified as fair and excellent, while for pastures with more than 5 years of implantation, 80% are classified as poor and very poor. This can be related to soil fertility loss, that determines the decrease of the vigour of the pasture (genus *panycum*).

Previous works (Gunbarzewski, 1974; Santos e Novo, 1977) showed that LANDSAT images can be used for environmental planning. Santos e Novo (1977) concluded that the analysis of photographic texture in channel 7 permits the discrimination of the topomorphological units which are associated to different patterns of dissection degree.

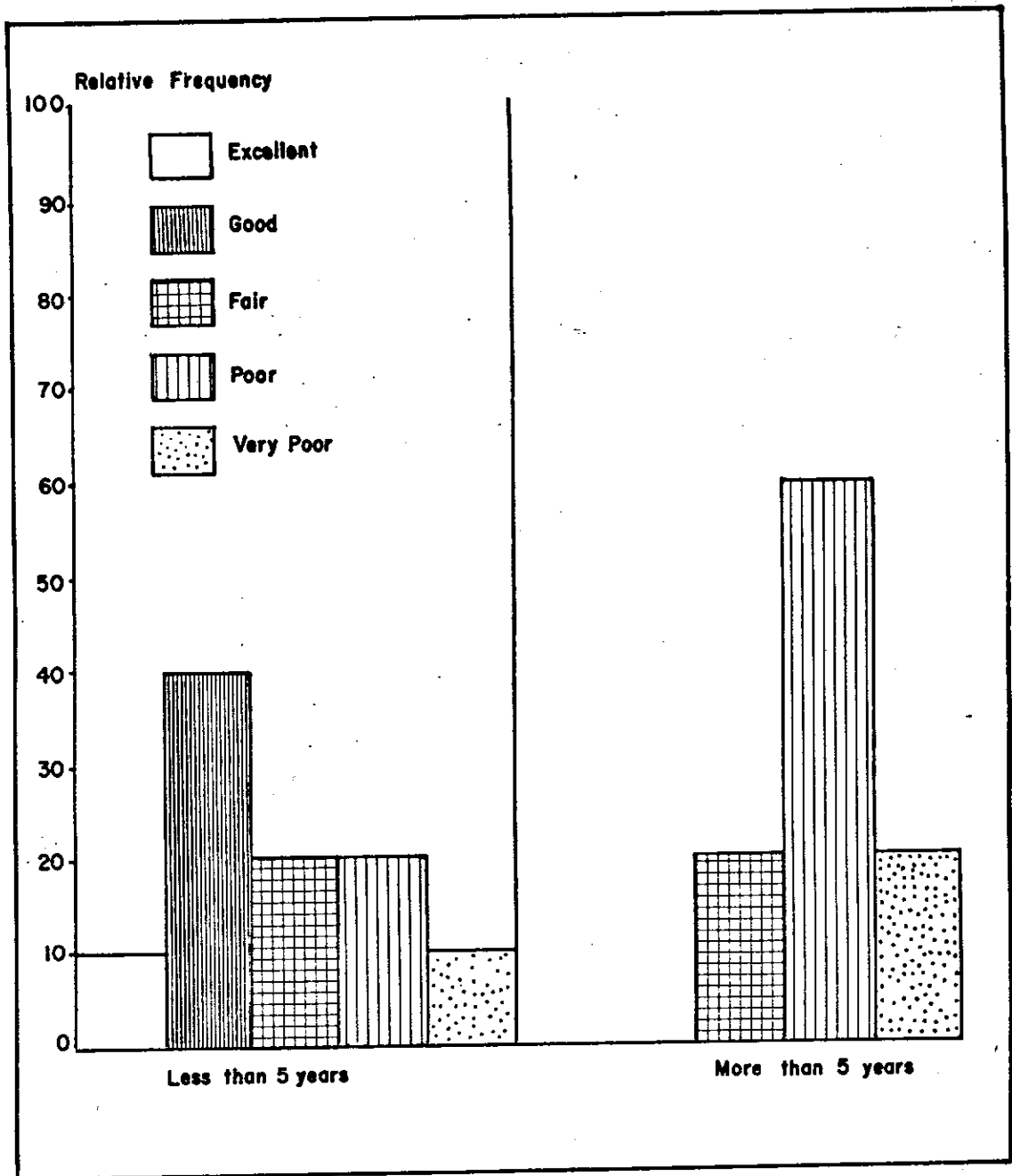


Fig. III.7 - Pasture quality versus occupation time diagrama.

The topomorphologic mapping was done in the Paragominas region and the proposed legend (based on ENPM's legend) took into account the data collected in the field, the scale and the resolution of the remote sensing system utilized. Five units were mapped: alluvial plain (AP); upper erosional plateau (UEP); lower erosional plateau (LEP); table dissected watersheds (TDW) and gully dissected watersheds (GDW).

Through the field data it was observed that the presence of lateritic soil was not a diagnostic factor for the pastureland quality. 33% of the analysed pastures with the presence of lateritic soil and 34% of pastures without it were classified as fair. Therefore, there are other factors that determinate the pasture quality in the Amazon region.

Table III.2 shows the distribution of the lateritic soil by the geomorphological units. It can be observed that the majority of lateritic soils are concentrated in lower and upper plateau. But most of the samples were located in the unit TDW.

TABLE III.2

PERCENTAGE OF LATERITIC SOIL BY TOPOMORPHOLOGIC UNIT

GEOMORPHOLOGICAL UNITS	PASTURE (%)	
	WITH LATERITIC SOIL	WITHOUT LATERITIC SOIL
AP	0	100
UEP	33	67
LEP	100	0
TDW	2	98
GDW	0	100

Table III.3 shows the overall effect of topomorphologic units over the pasture quality according to the ground data and LANDSAT images. It can be verified that the best pasture are implanted on the units LEP (100%), AP (50%) and TDW (36.9%). The unit GDW presented the poorest pasture quality which can be correlated to the runoff on undulating relief and consequently decrease in organic matter content. Considering the low fertility of the Amazon soils, the analysis of LANDSAT images can guide the implantation of pasture in areas with less problems of degradation.

In the evaluation of the quality pasture the main goal was to verify how many number of pasture classes could be discriminated through computer-aided analysis of LANDSAT data.

The genus *Panicum* is the most predominant specie in the study region. A good pasture management can provide forage during all over the year, even in the dry season. Unfortunately, the Paragominas region presents soils with very low level of fertility, that causes in the dry season a decrease of grass growth and consequently an increase of natural vegetation regrowth or exposed soil.

The degradation of pasture quality after deforestation was estimated according to the presence of no-grazing species, exposed soil and areas with grass coverage. Another way of doing it was to evaluate the change from *Panicum* species (that need high fertility soil) to *Hiparphenia* and *Brachiaria*.

TABLE III.3
PASTURE QUALITY (%) BY TOPOMORPHOLOGIS UNIT

PASTURE QUALITY TOPOMORFOLO GIC UNITS	PASTURE (%)					
	EXCELLENT	GOOD	FAIR	POOR	VERY POOR	TOTAL
AP		50.0		50.0		100.0
LEP		100.0				100.0
TDW	5.9	31.0	21.0	42.1		100.0
GDW			25.0	75.0		100.0
UEP		33.3		33.3	33.4	100.0

Based on the conditions observed on the field, 14 classes were defined:

- 1) upland forest;
- 2) arboreal "juquira" - regenerated from species common to upland forest;
- 3) herbaceous "juquira" - regenerated from species adapted to soils with very low fertility;
- 4) partially exposed soil - presence of legume and grass species, "juquira" and predominance of exposed soil;
- 5) bare soil - very low percentage of grass species and "juquira";
- 6) lateritic soil - without presence of grass species, very sparse "juquira" and high content of iron oxide;
- 7) pasture with *Panicum* species;
- 8) pasture with *Panicum* species and *Brachiaria humidicula*;
- 9) pasture with *Panicum* and *Hiparrhenia* species;
- 10) pasture with *Panicum* and presence of "juquira";
- 11) pasture with *Panicum* species and exposed soil;
- 12) pasture with *Panicum* and *Pueraria* species;
- 13) pasture with *Panicum* and *Brachiaria* species, and
- 14) floodplain.

Automatic classification was carried out to discriminate the different classes of pastures by using the MAXVER algorithm (Velasco et al., 1978). This algorithm uses the maximum likelihood decision rule.

During the analysis there were some misclassification. The "bare soil" class was overlapped with the class "*Panicum* species with exposed soil". This can be explained by the fact that the two classes have the same element; exposed soil.

The class "pasture with *Panicum* " presented overlapping with the class "arboreal juquira". This could be observed in humid areas where the grass did not show moisture stress during the dry season, presenting similar spectral response as the arboreal juquira.

The herbaceous "juquira" class was found in pastures with more than 5 years of implantation. This could be explained by the management applied to that region, which consists in clearing and burning periodically the pastures and consequently causing the loss of soil fertility.

The partially exposed soil class is frequent in older pastures and pastures being implanted. The lateritic soil class presented soils without seed germination.

After automatic analysis of LANDSAT data, the 14 classes were regrouped into 4 new classes according to their importance for grazing:

- 1) "juquira" class - arboreal and herbaceous juquira;
- 2) bare soil - exposed soil and lateritic soil;
- 3) pasture class - includes *Panicum*, *Panicum/Brachiaria*, *Panicum/Hiparrhenia* and *Panicum/Pueraria* species; and
- 4) degraded pasture - partially exposed soil and *Panicum* with exposed soil.

Table III.4 shows the percentage occupied by these new classes. It can be seen that 45.47% of the deforested area (54,955 ha) are occupied by good pastures, 24.48% by "juquira", and 15.26% by degraded pasture (which needs high management technology). The exposed soil class presents the same problem as mentioned above, but when in the presence of lateritic soil, another seeding become necessary.

TABLE III.4

DISTRIBUTION OF CLASSE BY AUTOMATIC INTERPRETATION

CLASSES	AREA (Ha)	PERCENT
Juquira	13,453	24.48
Bare soil	8,072	14.69
Pasture	25,045	45.57
Degraded Pasture	8,385	15.26
T O T A L	54,955	100.00

The result showed that it is possible to make an evaluation of pasture degradation after deforestation through automatic classification. Also it was demonstrated that there exist a close correlation between pasture quality and occupation time. Normally, heavy degradation starts after the fifth year of implantation, what means that there is a lack of good management in the areas planned for pastureland.

The main problem for the region under study was the lack of researches which could lead farmers to explore pasturelands in an operational basis without affecting the environment.

REFERENCE

- ANUTA, P.E.; KRISTOF, S.J.; LEVANDOWSKI, D.W.; PHILLIPS, T.L.; MacDonald, R.B. Crop, soil, and geological mapping from digitized multispectral satellite photography. In: INTERNATIONAL SIMPOSIUM ON REMOTE SENSING OF ENVIRONMENT, 7., An Arbor, MI, 1971. Proceedings. V.3, p. 1983-2016.
- AOKI, H.; SANTOS, J.R. dos Fatores ambientais dos cerrados e imagens orbitais. *Boletim Técnico do Instituto Florestal*, nº 31, set. 1979.
- ASHLEY, M.D.; DETHIER, B.E. Phenological determinations from satellite and terrestrial sensor systems. In: PANAMERICAN SYMPOSIUM ON REMOTE SENSING, 1., Panamá, 1973. Proceedings. p. 137-146.
- BORDEN, F.Y.; MEREMBECK, B.F.; THOMPSON, D.N.; TURNER, B.J.; WILLIAMS, D.L. Classification and mapping of coal refuse, vegetative cover types, and forest types by digital processing ERTS-1 data. In: INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT, 9., Ann Arbor, MI, 1974. Proceedings. v. 1, p. 133-152.
- FERRI, M.G. Os cerrados de Minas. *Ciência e Cultura*, 27(11): 1217 - 1220, nov., 1975.
- GHILARDI, E.; MAINIERI, C. Caracterização e aplicações das madeiras nacionais no Estado de São Paulo. *Silvicultura em São Paulo*. (3): 311-322, 1964.
- GIMBARZEVSKY, P. ERTS-1 Imagery in Biophysical Studies. In: CANADIAN SYMPOSIUM ON REMOTE SENSING, 2., Ottawa, 1974. Proceedings. V.2, p. 391-404.
- GOODENOUGH, D.; SHLIEN, S. *Automatic classification methodology*. Ottawa, Canada Center for Remote Sensing. Department of Energy, Mines and Resources, 1974

- GOODLAND, R. *An ecological study of the cerrado vegetation of South-Central Brazil*. Thesis submitted to the Faculty of Graduate Studies and Research of McGill University, Montreal. 224p. mimeografada.
- HILWIG, F.W.; GOOSEN, D.; KATSIERIS, D. Preliminary results of the interpretation of ERTS-1 imagery for a soil survey of the Merida Region, Spain. *ITC Journal*, 3:289-312, 1974.
- HOFFER, R.M.; JOHANNSEN, C.J. Ecological potentials in spectral signature analysis. In: PURDUE UNIVERSITY. LARS. *Remote sensing technology and applications*. Lafayette, IN., 1972. p. 1-26 (LARS Print 011069-R)
- INSTITUTO BRASILEIRO DE DESENVOLVIMENTO FLORESTAL (IBDF) Análise da unidade de conservação. In: ———. Plano de manejo. Parque Nacional da Amazonia (Tapajós). Brasília, 1978. cap. 2, p. 44-60.
- KAN, E.P.; DILMAN, R.D. Timber types separability in south-eastern United States on LANDSAT-1 MSS data. In: NASA. *Earth Resources Survey Symposium* held in Houston, TX., June, 9-12, 1975. Proceedings. v.1-A, p. 135-157.
- KING, R.B.; RAINS, A.B. A comparison of ERTS imagery with conventional aerial photography for land-resource surveys in less developed countries. Examples from the Rift Valley Lakes Basin, Ethiopia. In: EROS. *European Earth Resources Satellite Experiments: Symposium* held at Frascati, Italy, Jan., 28 - Feb., 1, 1974. Proceedings. p. 371-379.
- LAUER, D.T. Multispectral sensing of forest vegetation. *Photogrammetric Engineering*, 35(4):346-354, Apr., 1969.
- MAXWELL, E.L. Application of ERTS to rangeland management. In: SHAKROKHI, F.; ed. *Remote sensing of earth resources*. Tullahoma, TN., University of Tennessee, 1975a. v.4, p. 105-135.

- MYERS, V.I.; HEILMAN, M.D. Thermal infrared for soil, temperature studies. *Photogrammetric Engineering*, 35(10):1024-1032, Oct., 1969.
- NOSSEIR, M.K.; PALESTINO, C.V.B.; BATISTA, G.T. *Mapeamento da Vegetação Natural dos Estados de Minas Gerais e do Espírito Santo (Região Leste do Brasil), através de Imagens MSS do ERTS-1*. São José dos Campos, INPE, Fev., 1975. (LAFE-617).
- PANDOLFO, C. *A floresta Amazônica brasileira - enfoque econômico/ecológico*. SUDAM, Belém, 1978.
- PARKS, W.L.; BODENHEIMER, R.E. Delineation of major soil associations using ERTS-1 imagery. In NASA. *Symposium on Significant Results Obtained from the Earth Resources Technology Satellite - 1: Symposium held at New Carrollton, MD., Mar., 5-9, 1973, Proceedings. v.1-A*, p. 121-126.
- PINTO, J.H.D.; SANTOS, J.R. dos; CHIANG, L.C.; NIERO, M.; PINTO, S.A. F.; CARVALHO, V.C. de *Levantamento integrado dos recursos naturais da área do Parque Nacional da Amazonia (Tapajós), baseado nas imagens MSS do LANDSAT*. São José dos Campos, INPE, set, 1979. (INPE-1577-RPE/074).
- SAFIR, G.R.; MYERS, W.L.; MALILA, W.A.; MORGENSTERN, J.P. Application of ERTS-1 data to analysis of agricultural crops and forests in Michigan. In: NASA. *Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1*. Symposium held at New Carrollton, MD., Mar. 5-9, 1973. Proceedings. v.1-B, p. 173 - 180. (NASA SP-327).
- SANTOS, A.P. dos; NOVO, E.M.L.M. *Avaliação do uso de dados do LANDSAT-1 na implantação, controle e acompanhamento de projetos agropecuários no sudoeste da Amazônia legal*. Tese de Mestrado em Sensoriamento Remoto e Aplicações. São José dos Campos, INPE, 1977. (INPE-1044-IPT/056).

- SANTOS, J.R. dos *Utilização de imagens do LANDSAT e fotografias do Skylab, para o levantamento de vegetação, relevo e caracterização de áreas de maior potencial agrícola no sul do Estado do Espírito Santo.* São José dos Campos, INPE, out., 1976. (INPE-957-NTE/071)
- SANTOS, J.R. dos; CARVALHO, V.C. de; AOKI, H. *Characterization of Cerrado vegetation using automatically classified LANDSAT MSS data.* São José dos Campos, jun., 1980. (INPE-1790-RPE/162)
- SANTOS, J.R. dos; LEE, D.C.C.; COLAÇO, L.H.; CRUZ, E.C. da; SILVA, L. C.S.; AQUINO, L.C.S. de; COSME, J.R.; BALBI, L. *Vegetação e uso atual da terra.* In: INSTITUTO DE PESQUISAS ESPACIAIS (INPE). *Projeto Amazonas: sensoriamento remoto aplicado ao levantamento de recursos naturais.* São José dos Campos, INPE, mar., 1981. cap. 2, p. 5-21. (INPE-2019-NTE/166)
- SCHRUMPF, B.J. *Natural vegetation inventory.* In: NASA. *Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1: Symposium held at New Carrollton, MD., Mar., 5-9, 1973. Proceedings.* v. 1-A, p. 59-66. (NASA SP-327)
- SIEGAL, B.S.; GOETZ, A.F.H. *Effect of vegetation on rock and soil type discrimination.* *Photogrammetric Engineering and Remote Sensing*, 43(2):191-196, Feb., 1977.
- SMITH, W.K.; NOBEL, P.S. *Influences of seasonal changes in leaf morphology on water-use efficiency for three desert broadleaf shrubs.* *Ecology*, 58(5):1033-1043, 1977.
- STRAHLER, A.N. *Quantitative analysis of watershed geomorphology.* *Transactions, American Geophysical Union*, 36(6): 913-920, Dec., 1957.
- SWAIN, P.H.; KING, R.C. *Two effects feature selection criteria for multispectral remote sensing.* West Lafayette, IN Purdue University. LARS, 1973. (LARS Information Note 042673).

- UNIVERSIDADE FEDERAL DO PARANÁ. CENTRO DE PESQUISAS FLORESTAIS. *Estudo das alternativas técnicas, econômicas e sociais do setor florestal do Paraná* - subprograma matéria prima. Curitiba, 1974.
- VALÉRIO FILHO, M.; HIGA, N.T.; CARVALHO, V.C. de *Avaliação das imagens orbitais (LANDSAT-1) como base para o levantamento de solos*. Tese de Mestrado em Sensoriamento Remoto e Aplicações. São José dos Campos, INPE, 1976. (INPE-912-TPT/030)
- VELASCO, F.R.D.; PRADO, L.O.C.; SOUZA, R.C.M. *Sistema MAXVER: manual do usuário*. São José dos Campos, INPE, jul., 1978. (INPE-1315-NTI/110).
- WEBER, F.P.; ALDRICH, R.C.; SADOWISKI, F.G.; THOMSON, F.J. Land use classification in the Southeastern Forest Region by multispectral scanning and computerized mapping. In: INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF ENVIRONMENT, 8., Ann Arbor, MI., 1972. Proceedings. v.1, p. 351-373.
- WESTIN, F.C.; MYERS, V.I. Identification of soil associations in Western South Dakota on ERTS-1 imagery. In: NASA. *Symposium on Significant Results Obtained from the Earth Resources Technology Satellite-1*: Symposium held at New Carrollton, MD., Mar., 5-9, 1973. Proceedings. v.1-B, p. 965-972.
- WIEGAND, C.L.; GAUSMAN, H.W.; CUELLAR, J.A.; GERBERMAN, A.H.; RICHARDSON, A.J. Vegetation density as deduced from ERTS-1 MSS response. In: EARTH RESOURCES TECHNOLOGY SATELLITE-1 SYMPOSIUM, 3., Washington D.C., 1973. Proceedings. v.1-A, p. 93-116.
- WILLIAMSON, D.T. Vegetation mapping from ERTS imagery of the Okavango Delta. In: EARTH RESOURCES TECHNOLOGY SATELLITE SYMPOSIUM, 3., Washington D.C., 1973. Proceedings. v.1-A, p. 301-308.
- WONG, K.W.; THORNBURN, T.H.; KHOURY, M.A. Automatic soil identification from remote sensing data. *Photogrammetric Engineering and Remote Sensing*, 43(1):73-80, Jan., 1977.

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