



PALAVRAS CHAVES/KEY WORDS

AUTORES / AUTHORS
LANDSAT-TM IMAGES
DEFORESTATION
LEGAL AMAZONIA

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CDU/UDC

528.711.7:634.0.32(811.3)

DATA / DATE

Jan. 1990

TÍTULO/TITLE	PUBLICAÇÃO Nº PUBLICACION NO INPE-5015-RPE/609
	EVALUATION OF DEFORESTATION IN THE LEGAL AMAZONIA USING LANDSAT-TM IMAGES
AUTORES/AUTHORSHIP	Antonio Tebaldi Tardin Roberto Pereira da Cunha

ORIGEM
ORIGIN
DPA

PROJETO
PROJECT
PRODES

Nº DE PAG.
NO OF PAGES
38

ULTIMA PAG.
LAST PAGE
A.5

VERSÃO
VERSION

Nº DE MAPAS
NO OF MAPS

RESUMO - NOTAS / ABSTRACT - NOTES

Results of measurements on the deforestation of the Brazilian Amazonian forest (Legal Amazonia) are presented. The study was based on most recent satellite remote sensing data acquired by the LANDSAT-5 satellite, Thematic Mapper sensor (TM). The study area comprises the limits of the Legal Amazonia (i.e. 4,906,785 sq km) which corresponds to almost 60% of the Brazilian territory. Visual interpretation techniques were applied in the analysis of color composites, LANDSAT-TM bands in the channels 3, 4 and 5, at the scale 1:250,000 in order to obtain the deforestation measurements. Only the deforestation rate for the forest domain was taken into account in this work. Data of acreage measurements are presented on a State by State basis and totalized for the whole Legal Amazonia. LANDSAT color composites were an efficient tool in the discrimination of the different types of deforestation. Percentually, Rondonia was the most deforested area of the Amazonia region (12.6%). The total deforested area of the Legal Amazonia points to a value of 251,426 sq km which is equivalent to 5.12% of the physical area of the Legal Amazonia since its establishment in 1953.

OBSERVAÇÕES / REMARKS

This work was carried out with the technical cooperation of researchers and remote sensing specialists of the Institute for Space Research.

RESUMO

Este trabalho teve como objetivo utilizar as imagens mais recentes obtidas pelo satélite LANDSAT-TM na avaliação da alteração da cobertura florestal da Amazônia Legal, cuja superfície corresponde a 57,6% do território brasileiro. Foi utilizada técnica de interpretação visual de composições coloridas obtidas dos canais 3, 4 e 5 do TM na escala de 1:250.000. Foram levadas em consideração as alterações em áreas sob domínio da vegetação com fisionomia florestal. Dados quantitativos da cobertura florestal são apresentados por Unidade Federativa e para a Amazônia Legal na forma de tabelas e gráficos. As composições coloridas utilizadas neste trabalho permitiram a caracterização dos diferentes tipos de alteração da cobertura florestal. Até 1988, Rondônia foi a Unidade Federativa da Amazônia que apresentou o maior índice percentual de desmatamento (12,6%). A Amazônia como um todo apresenta uma superfície florestal alterada de 251.426km² o que equivale a 5,12% da área física da Amazônia Legal desde sua criação em 1953.

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CONTENTS

	<u>PAGE</u>
LIST OF FIGURES.....	v
<u>CHAPTER 1 - INTRODUCTION</u>	1
<u>CHAPTER 2 - MATERIALS AND METHODS</u>	5
2.1 - Description of study area.....	5
2.2 - Materials.....	7
2.3 - Methods.....	7
<u>CHAPTER 3 - RESULTS AND DISCUSSION</u>	9
3.1 - Landsat-TM images.....	9
3.2 - Image analysis.....	11
3.3 - Quantitative data and relative values of deforestation areas.....	13
<u>CHAPTER 4 - CONCLUSIONS AND SUGGESTIONS</u>	23
REFERENCES.....	27
APPENDIX	

LIST OF FIGURES

	<u>PAGE</u>
2.1 - Legal Amazonia study area.....	6
3.1 - Map of image localization with the correspondent acquisition dates.....	10
3.2 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Acre and Amazonas States, and Amapá Territory.....	19
3.3 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Pará and Rondonia States, and Roraima Territory.....	20
3.4 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Tocantins-Goiás, Maranhão and Mato Grosso States.....	21
3.5 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Legal Amazonia.....	22

CHAPTER 1

INTRODUCTION

In the middle of the 70's, the Amazonia Development Agency (SUDAM) ordered at the Institute for Space Research (INPE) a study on the use of Landsat satellite imageries to evaluate pasture projects being established in the Legal Amazonia with fiscal incentives delivered by the Federal Government. The rationale was based on the difficulties of SUDAM to perform the inspection of these projects through conventional methods.

Results obtained in previous works carried out in agreement between INPE and SUDAM showed the efficiency of orbital images in the detection and evaluation of deforestation even those considered "old deforestation" which means, large areas of former forest cover observed in Pará and Maranhão States. These areas were changed by man-induced activities many years before the pasture project implantation started at the early 60's. Besides the deforestation it was also possible to evaluate the pasture quality using LANDSAT data (Santos e Novo, 1977). Research was conducted to study the relationship between soil degradation in the Amazonia and the spectral responses of Landsat data as well as the

correlation between pasture quality and the time of pasture implantation (Santos et al., 1979a).

In 1977, a technical cooperation agreement was signed between INPE and the Brazilian Institute for Forestry Development (IBDF) with the objective of applying orbital remote sensing techniques to forest resources survey purposes. In 1978 the Deforestation project was carried out. The study area comprised the Territory of Rondonia, now it corresponds to the State of Rondonia (Santos et al., 1979b). The significant results obtained in that year suggested to continue this project in 1979 for the whole Legal Amazonia using Landsat images of two different dates (Tardin et al., 1980).

In the following years, other surveys on deforestation were done in some States but not in the Legal Amazonia as a whole (IBDF, 1983, 1988).

Along the 80's some deforestation estimates were done in Amazonia based on mathematical projections (Fearnside, 1982, 1989; Mahar, 1989), without using remote sensing data. These mathematical projections mean different hypothesis, quite different of this present work which considers actual measurements from Landsat data.

This work presents a study that uses the most recent images acquired by Landsat-TM satellite to evaluate the deforestation of Legal Amazonia.

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CHAPTER 2

MATERIALS AND METHODS

2.1 - DESCRIPTION OF STUDY AREA

The study area comprises the total Legal Amazonia which represents a political boundary and has served as a basis for government development policies.

The Legal Amazonia according to the Federal Government decree of 1953, encompasses the States and Territories of Acre, Amapá, Amazonas, Pará, Rondônia and Roraima, and part of the Tocantins-Goiás States (north of the parallel 13°), the Mato Grosso State (north of the parallel 16°) and the Maranhão State (west of the meridian 44°) with an area of $4,906,785\text{km}^2$ (Figure 2.1).



Fig. 2.1 - Legal Amazonia study area.

2.2 - MATERIALS

Mosaics assembled with Landsat-TM images channel 3, at the scale of 1:1,000,000 were available for the whole Legal Amazonia as well as paper print color composites at the 1:250,000 scale obtained from the Landsat-TM bands 3, 4 and 5 with blue, green and red filters respectively, and thematic maps of RADAMBRASIL Project at the scale of 1:1,000,000. Furthermore, materials such as millimeter grid cell, planimeter, overlays, and others were used.

2.3 - METHODS

The following methodological procedure was used in this work:

- a) visual analysis of Landsat-TM mosaics at 1:1,000,000 scale that permitted the selection of images which showed deforested patterns. The forest types considered here were those used by the RADAMBRASIL Project, and classified as: Closed Forest, Open Forest, Deciduous Forest, Woodland Forest, Ecological Tension Areas, Pioneer Formations, etc.
- b) Visual interpretation of color composites obtained from Landsat-TM channels 3, 4 and 5 at the scale of

1:250,000. These bands were chosen due to the high sensitivity of the band 4 (near infrared) to the internal structure of the leaf; the low response of band 3 (red portion of the spectrum) due to the chlorophyll absorption, and the band 5 (middle infrared) which is sensitive to leaf water content. This color composite permits the discrimination between native forest and deforested areas, even the older deforested areas which were considered apart following the same procedure used by Tardin et al. (1980) because the major difficulty is related to the deforestation that started in the 60's.

In this work, those vegetation formations with forest physiognomy were considered, including particularly the "Cerradão". The vegetation maps of RADAMBRASIL were utilized to draw the contact forest/cerrado.

A millimeter grid cell was used in the area evaluation. Large continuous deforested areas were measured with a planimeter.

Quantitative data of deforested areas were presented in figures and tables by State, Territory, and for the entire Legal Amazonia.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 - LANDSAT-TM IMAGES

Figure 3.1 shows the map with the localization of images used in this work. From a total of 101 images selected, 73 were acquired in 1988, 19 were from 1987 and 4 were obtained from cerrado which is a non-forest vegetation. The other 9 images were distributed as follows: for 1986 (4), 1985 (4), and 1984 (1). From these, 4 images were localized in the extreme north of Legal Amazonia where the deforestation intensity is very low. It can be seen that 73% of images were obtained in 1988. The sum of 1988 images plus 1987 images corresponds to 91.7% of the total images interpreted. This was the state-of-art over deforestation in the Legal Amazonia until march, 1989.

The Appendix presents the Landsat-TM images row/path , and the acquisition dates of all images used in this work.

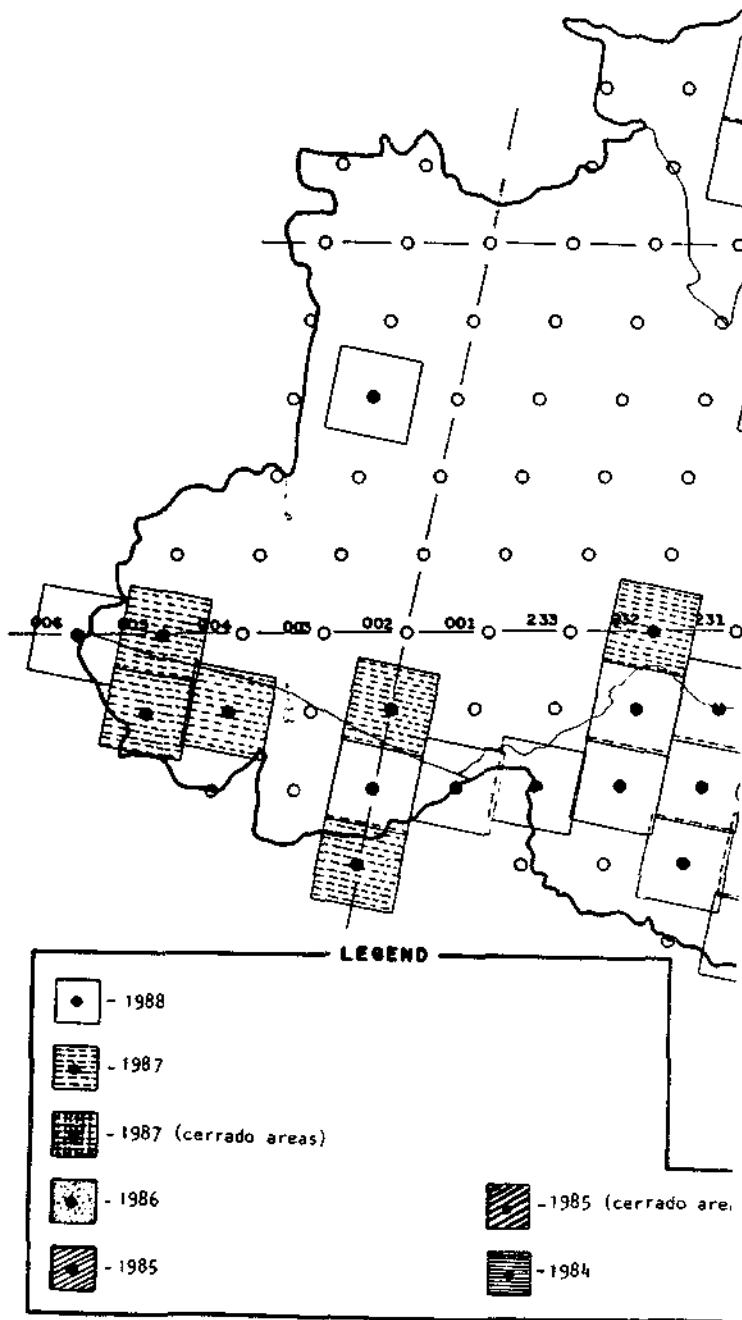


Fig. 3.1 - Map of image localization with the correspondent acquisition dates.

The year of 1988 was excellent in terms of cloud free image acquisition over the Legal Amazonia. This good condition permitted to show an actual situation of that region in relation to its forest cover in a recent year (1988).

3.2 - IMAGE ANALYSIS

Color composites obtained from Landsat-TM channels 3, 4 and 5 with high quality, were used. These images were much better than those used by Tardin et al., (1980). In that time, black and white MSS bands 5 and 7, at a scale of 1:500,000 were used. Another difficulty was the number of images to be interpreted. The total amount of images necessary to cover the whole Legal Amazonia area for both studies (Tardin et al., 1980 and the present work) was quite different: the actual study used only one color composite per row/path at a larger scale (1:250,000) with high spatial resolution (30m compared to the 80m of MSS). So it became easier to detect deforested areas. The image interpretation was based on spectral and spatial aspects (tonalities and shapes) of areas with forest physiognomy in Legal Amazonia.

Deforested areas with none or low vegetal coverage appear as pink on the images. Recently burned areas

show dark tones. These burned areas were not frequently observed in the analyzed imageries on the forest domain. Water surface of the artificial reservoirs is also a type of former forest cover; it shows dark tones, quite similar to burned areas but they have different shapes. Burned areas of forests present regular shapes while the perimeter of the reservoirs follows the drainage pattern.

Old deforested areas occupy large tracts on a continuous way. They present two different patterns in the images: pink color when a recent vegetation change was done and yellowish, that indicates a secondary vegetation. Native forests present a deep green tonality or green brownish in some areas of Amazonia. Urban areas show the same pattern of those changed areas with very low vegetal coverage or completely bare. Agriculture colonizations have a very conspicuous pattern called "fishbone" (espinha de peixe).

As far as the pasture projects are concerned, there is a predominance of large deforested areas with regular shapes. The vegetation class of "Campos Cerrados" which is present within the forest domain, shows similar patterns of recent deforestations but it can be discriminated considering the spatial aspects (irregular shapes) as well as by using the vegetation maps of RADAMBRASIL Project.

3.3 - QUANTITATIVE DATA AND RELATIVE VALUES OF DEFORESTATION AREAS

Table 3.1 summarizes quantitative data on deforestation by State, Territory and for the Legal Amazonia until 1988, and the corresponding relative values. It can be observed that the greatest rates of deforestation occur in the States of Rondonia, Tocantins, Goiás, Maranhão, and Mato Grosso which have a higher density of roads that helps the human penetration in that region.

The State of Rondonia has been intensively occupied in the decade of 80. Until 1988 it was the most deforested State of the Legal Amazonia in relative terms, not being considered here the old deforestations of the States of Pará (31,822km²), and Maranhão (60,724km²).

Actual measurements of deforestation acreage were performed based on Landsat-TM imageries at 1:250,000 scale. For the total Legal Amazonia, a value of 251,426km² was calculated with a high level of accuracy, considering the quality of the images analyzed and the acreage evaluation. According to Tardin et al. (1984) using Landsat-TM images at the same scale (1:250,000), acquired over the sugar cane region in the north of Rio de Janeiro State reached an error of less than 5% in the area evaluation, when the sugar cane

fields were greater than 30 hectares. Considering that the majority of deforested areas of Legal Amazonia are greater than this value, one can conclude that the accuracy of area evaluation in the Legal Amazonia is greater than 95%.

Using mathematical projections, Fearnside (1982) did estimates for deforestation in the Legal Amazonia and obtained, surprising results like those for the Goiás and Rondonia States, which could be completely deforested until 1988. In a recent publication, Fearnside (1989) mathematically, estimated the total deforested area of Legal Amazonia to be 399,252km², (8.1%).

Mahar (1989), also using mathematical projections, estimated a deforested area of 598,921km² or 12% for the Legal Amazonia until 1988.

These estimates are inconsistent due to the lack of data in the period from 1975 through 1988. It is worthwhile to mention that different States or Territories have its own program, and that means: for each State or Territory a different approach must be taken into account.

TABLE 3.1
 DEFORESTATION BY STATE, TERRITORY, AND LEGAL AMAZONIA UNTIL 1988

STATES AND TERRITORIES (ST)	ST AREAS (km ²)	DEFORESTED AREAS UNTIL 1988 (km ²)	EQUIVALENT OF ST (%)	EQUIVALENT OF LAM (%)
Acre	153,698	5,509	3.58	0.11
Amapá	142,358	842	0.59	0.02
Amazonas	1,567,954	12,836	0.82	0.26
Pará	1,246,833	88,741*	7.12	1.81
Rondônia	238,379	30,046	12.60	0.61
Roraima	225,017	2,187	0.97	0.04
Tocantins - Goiás	269,910	20,279	7.51	0.41
Maranhão	260,233	23,771*	9.13	0.48
Mato Grosso	802,403	67,215	8.38	1.37
Legal Amazonia (LAM)	4,906,785	251,426	-	5.12

* Not included values of "old deforestation" (See text)

There are many types of deforestation in the Amazonia (Mahar , 1989), including agriculture, pasture for cattle grazing, logging, mineral exploration, dams, roads, urban and so on.

For the Legal Amazonia the cattle grazing activity is the most important to increase the deforestation rate. It started very fast during the decade of 60 due to the fiscal incentives delivered by the Federal Government. The construction of dams for hydroelectric power purposes is another activity that will increase the rate of deforestation in the next years but the road implantations that have occurred in a fast way is the major cause of the deforestation in the Legal Amazonia.

Table 3.2 shows the deforestation until 1978 and 1988 by State, Territory, and for the whole Legal Amazonia, and increment rates.

If one considers only absolute values, the greatest one was found for Pará State (6,630km²), while the greatest relative value was encountered in Roraima Territory with a rate of 1,429%, followed by the State of Amazonia, and the Territory of Roraima (619% and 618%, respectively) which

is explained by the low deforestation rates observed in these regions until the end of the 70's.

The annual mean increment on deforestation for the Legal Amazonia was 17,435km². In the period of 10 years, comprised from 1978 to 1988 a deforestation increase of 226% was reached.

These increments are better visualized on Figures 3.2, 3.3, 3.4, and 3.5 which show the altered areas quantitatively until 1975 and 1978 (Tardin et al., 1980), and deforested areas quantitatively until 1988 for each State and Territory, and for the whole Legal Amazonia.

TABLE 3.2

DEFORESTATION RATES UNTIL 1978 AND 1988 BY STATE, TERRITORY AND LEGAL AMAZONIA

STATES AND TERRITORIES	DEFORESTATION (km ²)		ANNUAL MEAN (km ²)	INCREMENT RATES	
	UNTIL 1978 (A) *	UNTIL 1988 (B)		PERIOD (%) (B-A)/A.100 ⁻¹	
Acre	2,464	5,509	304	124	
Amapá	170	842	67	395	
Amazonas	1,785	12,836	1,105	619	
Pará	22,445	88,741	6,630	295	
Rodônia	4,184	30,046	2,586	618	
Roraima	143	2,187	204	1,429	
Tocantins - Goiás	10,288	20,279	999	97	
Maranhão	7,334	23,771	1,644	224	
Mato Grosso	28,255	67,215	3,896	138	
Legal Amazonia	77,068	251,426	17,435	226	

* Tardin et al., 1980.

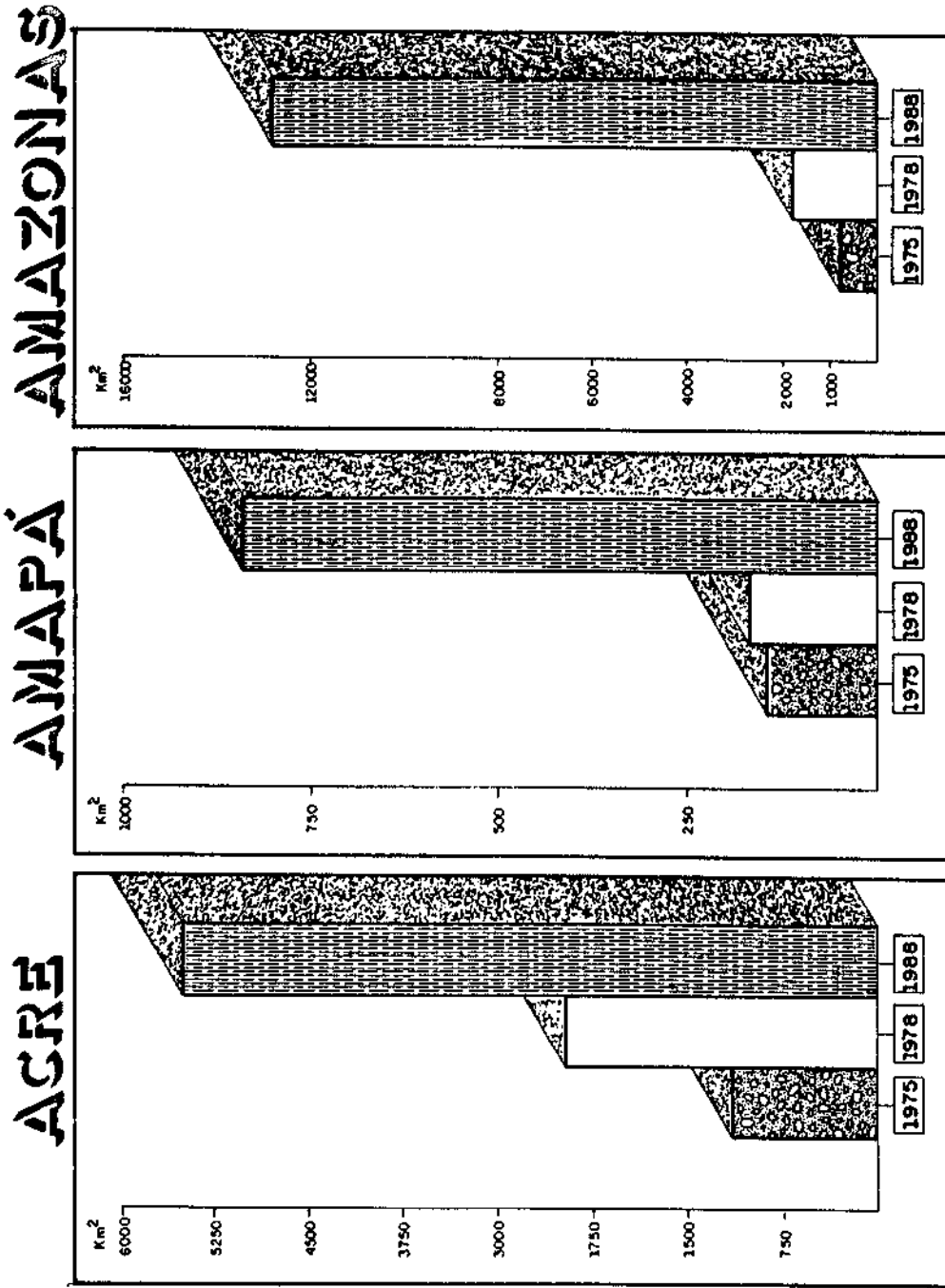


Fig. 3.2 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Acre and Amazonas States, and Amapá Territory.

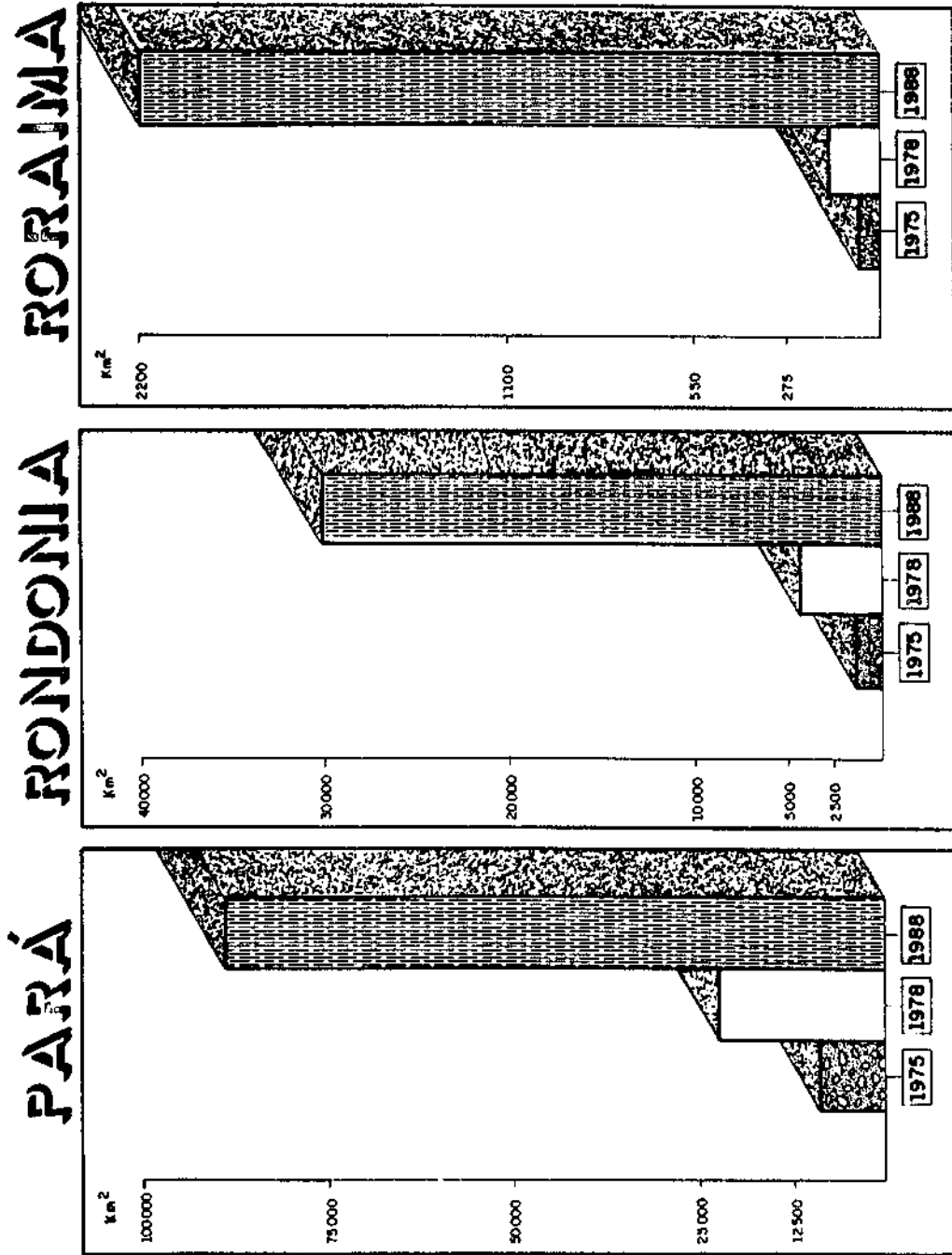


Fig. 3.3 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Pará and Rondônia States, and Roraima Territory.

TOCANTINS -GOIÁS MARANHÃO MATO GROSSO

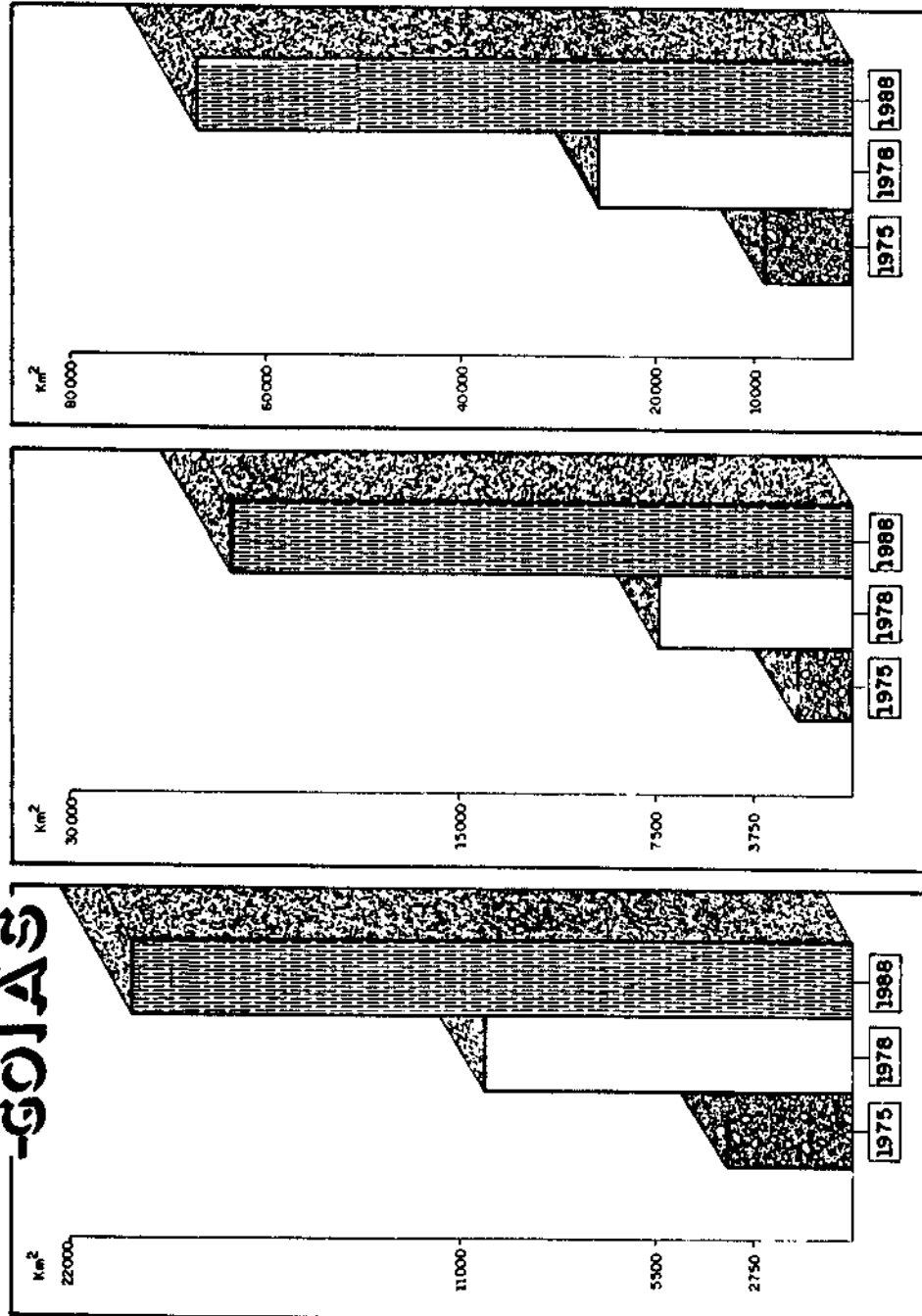


Fig. 3.4 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Tocantins-Goiás, Maranhão and Mato Grosso States.

LEGAL AMAZONIA

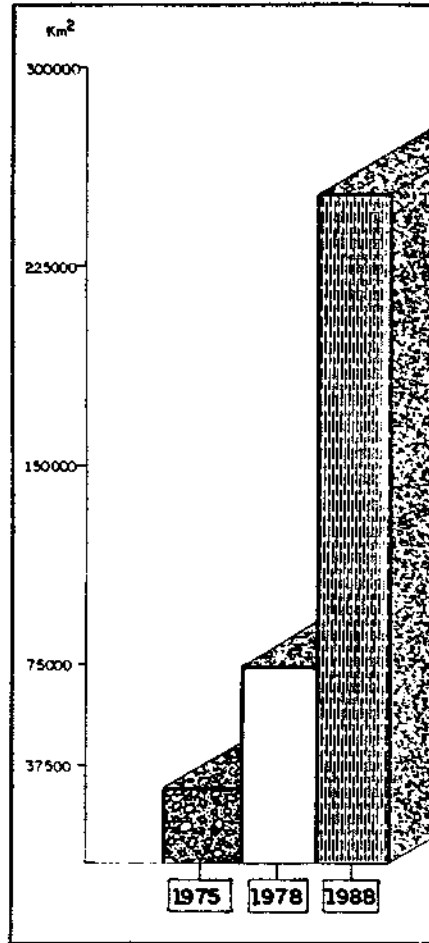


Fig. 3.5 - Quantitative data of altered vegetal cover until 1975 and 1978 (Tardin et al., 1980), and deforested areas until 1988 of Legal Amazonia.

CHAPTER 4

CONCLUSIONS AND SUGGESTIONS

Color composites of Landsat-TM bands 3, 4 and 5 permitted the detection of deforested areas. Exception is made to "Campos Cerrados" within the forest domain which could be discriminated, considering the spatial aspects (irregular shapes) and using as auxiliary data the vegetation maps of RADAMBRASIL Project.

The error in the acreage estimate is very low considering that most deforested areas in the Amazonia are very large.

Cloud cover of 1988 images did not affect the final results of this project since they were localized in areas with beginning human occupation activities. Images acquired in 1987 were also available, which can be considered very recent images.

The highest concentration of deforested areas are observed along the roads. This means that road constructions are the main cause of human activity in the Legal Amazonia.

The percentage of deforested areas in Legal Amazonia is very low when compared with mathematical projections. Nevertheless there are situations where the deforestation process occurred very fast like in the case of Rondonia during the 80's.

Burned areas were not very frequent at the images analyzed in this work.

It is very important to keep running a permanent monitoring system using satellite imageries, mainly over critical areas in terms of high deforestation rates as well as, national parks, Indian reserves, mineral exploration areas, and artificial water reservoirs.

A monitoring system for the Legal Amazonia is necessary, using orbital data on a digital way, and being processed in a geographical information system (GIS) which would permit the integration with other data sources.

Research must be carried out to improve the detection and monitoring of logging activities, and to study the pasture quality with emphasis in soil degradation.

Investigations toward the timber volume evaluation of tropical forest and floristic studies are recommended using a multistage approach.

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APPENDIX

LANDSAT-TM IMAGES ROW/PATH AND ACQUISITION DATES

PATH	ROW	DATE	
220	62	08.13.86	Partial cloud cover in 1988
	63	07.31.87	Partial cloud cover in 1988
221	61	09.15.84	Partial cloud cover in 1988
	62	06.17.86	Partial cloud cover in 1988
	63	07.24.88	
	64	08.09.88	
222	61	10.03.88	
	62	08.16.88	
	63	07.15.88	
	64	08.16.88	
	65	08.16.88	
	66	09.01.88	
223	67	09.01.88	
	61	09.24.88	
	62	09.24.88	
	63	09.24.88	
	64	08.07.88	
	65	08.23.88	
	66	08.23.88	
	67	08.07.88	
	68	09.08.88	
	69	09.24.88	
70	09.24.88		
224	71	09.08.88	
	62	07.21.85	Partial cloud cover in 1988
	63	08.14.88	
	64	08.14.88	
	65	07.13.88	
	66	07.13.88	
	67	08.14.88	
	68	08.30.88	
	69	10.15.87	Cerrado vegetation region
	70	08.30.88	
71	08.28.87	Cerrado vegetation region	

(Continued)

PATH	ROW	DATE	
225	60	07.02.87	Partial cloud cover in 1988
	61	07.15.86	Partial cloud cover in 1988
	62	07.20.88	
	63	09.06.88	
	68	07.02.87	Partial cloud cover in 1988
	69	08.03.87	Partial cloud cover in 1988
	70	06.26.85	Cerrado area
	71	11.09.88	
	72	11.09.88	
226	60	08.04.85	Partial cloud cover in 1988
	61	09.13.88	
	62	07.11.88	
	63	07.11.88	
	68	07.27.88	
	69	08.12.88	
	70	07.27.88	
	71	08.28.88	
227	61	07.23.84	Partial cloud cover in 1988
	62	08.03.88	
	63	07.18.88	
	65	07.02.88	
	66	07.02.88	
	67	07.16.87	Partial cloud cover in 1988
	68	08.03.88	
	69	09.20.88	
	70	09.20.88	
	71	11.07.88	
	72	07.17.87	Cerrado area

(Continued)

PATH	ROW	DATE	
228	61	09.27.88	
	62	06.18.86	Partial cloud cover in 1988
	63	08.24.87	Partial cloud cover in 1988
	64	06.23.88	
	68	08.10.88	
	69	07.07.87	Cerrado area
	70	08.10.88	
	71	07.25.88	
229	62	08.15.87	Partial cloud cover in 1988
	68	07.14.87	Partial cloud cover in 1988
	69	08.01.88	
	70	08.01.88	
230	61	09.07.87	Partial cloud cover in 1988
	62	09.25.88	
	63	09.25.88	
	68	08.08.88	
	69	08.08.88	
231	59	07.30.88	
	60	08.15.88	
	61	08.15.88	
	62	08.15.88	
	66	07.30.88	
	67	07.30.88	
	68	07.30.88	
232	58	10.09.88	
	59	10.09.88	
	65	07.03.87	Partial cloud cover in 1988
	66	06.19.88	
	67	06.19.88	

(Conclusion)

PATH	ROW	DATE	
233	67	07.28.88	
001	67	08.04.88	
002	66	09.10.87	Partial cloud cover in 1988
	67	07.26.88	
	68	09.10.87	Partial cloud cover in 1988
003	62	08.02.88	
004	66	06.20.87	Partial cloud cover in 1988
005	65	08.14.87	Partial cloud cover in 1988
	66	08.14.87	Partial cloud cover in 1988
006	65	08.23.88	Partial cloud cover in 1988