Monitoring of Amazonian Forest Ecosystem: Present Conjuncture on the Use of Remote Sensing Technology

JOÃO ROBERTO DOS SANTOS*

Instituto Nacional de Pesquisas Espaciais - UNPE, Caixa Postal 515,
12.270-010 São José dos Campos-SP

ABSTRACT

Taking into account the need of an upgrade on remote sensing applications on Ecology and Biodiversity studies, the objective of this paper is to show the state of the art of these technologies to monitor the forest cover and deforestation process occurring in the Brazilian Amazon Region. An analysis on the importance of orbital remote sensing data (Landsat/TM, ERS-1/SAR,...) was done in order to characterize land use changes. The present annual conversion rate of forests (mainly for pasture, agricultural use) in Amazonia is 0.26% per year. Furthermore, comments are made on the use of segmentation and classification of digital images together with GIS as a component of an Amazonia Database made by INPE. The use of NOAA/AVHRR data is demonstrated for the analysis of seasonal behavior of the vegetation cover as well as for the detection of biomass burning. A description is made of the results from SAREX mission in Amazonia (a Canadian airborne C-Band SAR), with simulations of RADARSAT, are described, in order to show the potential of new spaceborne radar sensor systems to identify abandoned deforested areas with natural regeneration process.

Key words: Monitoring, Forest Ecosystem, Remote Sensing, Amazonia.

INTRODUCTION

The conversion of tropical forest into areas of pasture and various agricultural uses could lead, according to Granger (1983), to an irreversible loss of plant and animal genetic resources, a reduction in the potentially extractable volume of timber from primary forest species, environmental degradation, and even changes in global climate. This process promoted, during the eighties, the production of global level documents which discussed causes and effects of this conversion on the carbon cycle and on other gases, as well as the social economical impact, through significant alteration of soil fertility and consequently of the support of agriculture. Some of these documents, mainly these dealing with Amazonia, presented deforestation rate estimations considered as alarming, up to values of 80,000 km2 (IPCC, 1992).

Concerned with the debate on values and answering to national and international communities, the Federal Government, through the National Institute for Space Research -INPE, agency of the Ministry of Science and Technology, concentrated efforts on the use of remote sensing techniques as an integrated tool to monitor the forest cover of the Brazilian Amazonia and to provide an insight of the land use increase rate.

As an introduction to this task, the use of this technology at orbital level was developed for the study of forest area conversion, with emphasis on two important focuses:

* E-mail: Jroberto@ltid.inpe.br

a) Mapping, Monitoring and Estimation of Deforested Areas in Amazonia, Insisting for the Future on Studies of the Complexity of use Patterns, Including Abandoned Deforested Areas in Process of Natural Regeneration of the Forest Cover.

For this activity, two types of data were used:

– High spatial resolution and low temporal resolution (LANDSAT, SPOT, ERS-1...)

– High temporal resolution and low spatial resolution (AVHRR,...)

b) Application of Land use Transformation Data to Empirical Models, as an Aid to Biogeochemical, Atmospheric Chemistry and Water and Energy Balance Studies.

The rapid loss of forest cover in most parts of Amazonia leads to a special urgency for preservation. One of the most important parameter of such efforts is to determine a series of protected representative ecosystems of the biological species rich formations. This inevitably involves questions of sizes, shape and range of connectability between preserve areas and other forest areas (Lovejoy et al., 1986).

More recently, the possibility to monitor the forest ecosystem of the Amazonia which allows a more detailed knowledge of spatial vegetation distribution and its levels of disturbance evidenced a third focus: *the evaluation of the capability of spectral, spatial and temporal characteristics of orbital data, to support ecology and biodiversity studies.*

ESTIMATION OF DEFORESTATION IN AMAZONIA

To achieve part of the major purpose of forest ecosystem monitoring, a project (named PRODES/INPE) was developed in order to determine the annual increase of raw deforestation using Thematic Mapper/LANDSAT images and so, to evaluate the tropical forest annual conversion rate. The color composite TM3 (red spectral region), TM4 (near infrared) and TM5 (mean infrared) 1:250,000 scale images were used by visual analysis to stratify forest cover from the non-forest one, besides to characterize and estimate areas in process of deforestation. It is convenient, only to illustrate the dimension of orbital data, to quote that 229 Landsat images are necessary to cover all Legal Amazonia and to provide at least one estimation per year.

It is convenient to remind that among the stratification of areas covered by forest physionomical-structural aspect vegetation, are, according to Santos et al. (1993), faces of *dense and open tropical ombrophilous forest, tropical seasonal forest, woodland savanna, oligotrophic woodland ("campinarana arbórea") and pioneer formations with fluviomarine influence (mangroves)*, among others.

With these satellite products from Landsat/Thematic Mapper and exploring their spatial and temporal resolution characteristics, it is possible to analyze also the complexity of the patterns of change in forest cover in Amazonia. This may be done from land use in small farm, in large farm, and vegetal (latex, timber) and mineral extraction, which result from this disturbance. The deforestation gross annual rate for the Amazonia is presented on Figure 1.

In the middle of the eighties, the mean rate was about 21.130 km2/year (equivalent to 0.54% per year), decreasing to half this value in 1991 and stabilizing now to values of 9.600 km2/year (equivalent to 0.26% per year). It is recognized today, even if not yet effective, that there is an initial process of consciousness and of culture oriented to the rational use of land, on a maintained basis. As a consequence of this and as a mean term prevision, the permanence of the value around this level of 9.600 km2/year (± 3%) may be established, provided there should not exist from the Federal Government fiscal incentive to implant new agricultural and stock raising projects and/or installation of new colonization posts.

The use of geographic information system (GIS) technology is important for the continuity of the project when considering the great volume of information contained in these surveys, associated to the timing of data logging and to the overlays which contain the spacial distribution of forest areas with or without disturbance. This apply to storage and analysis of data, as a mean to merge

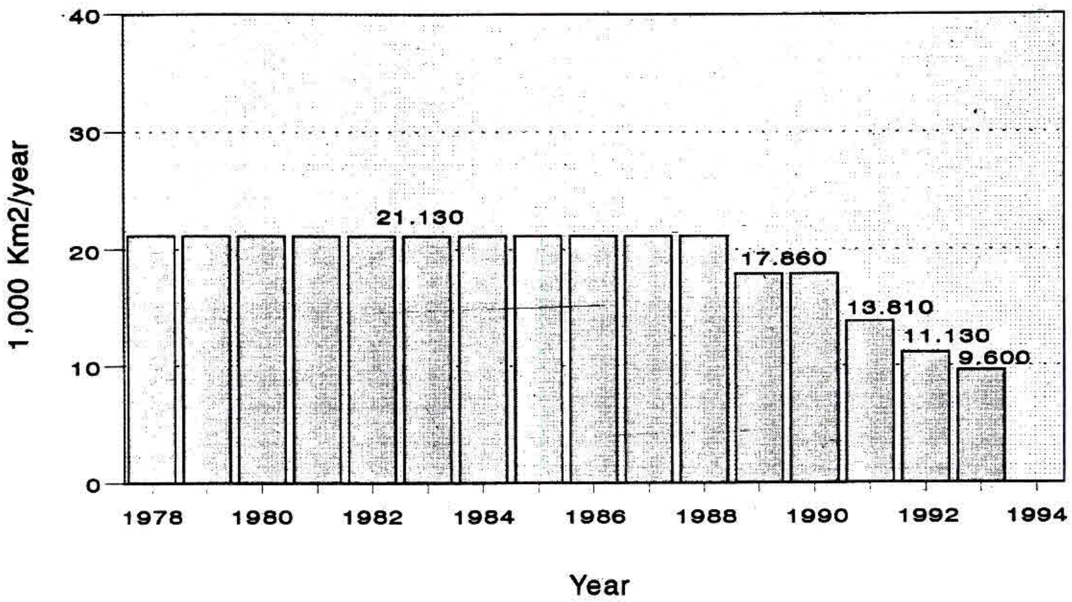

Fig. 1 — Annual gross rate of deforestation in Legal Amazonia. From: INPE, 1992 (modified).

satellite information to various sources, either of cartographic, numerical or geographic nature, to support plans of ecological/sustainable management for this wide region.

Presently, the INPE Amazonia Data Bank is made of 2/3 of 1:250,00 scale cartographic bases (MIR), from a total of 340 maps, which cover the Brazilian Amazonia. These bases contain the spatial distribution of deforested areas, for the 85-91 period, besides the limits between forest and non-forest, and the politico-administrative limits (Alves et al. 1992). All image visual analysis procedures are concluded, keeping the results which show the spatial distribution of disturbed areas in a temporal series, in the overlays used in the photo-interpretation phase. Besides this, 1/3 of the rest of the cartographic basis is not included in the Amazonia Data Bank. This is because these maps present a high complexity, due to the form and intensity of disturbed areas (as a simple example, the colonization in Rondônia State, named "fishbone"), which should need a great human effort in digitizing and lengthy computer processing time.

When dealing with the complexity of deforested areas, one must associate, as previously mentioned, the form of the disturbed area and the intensity of annual rate of variation, once the minimum area outlined in 1:250,000 scale Landsat color composite is 6.25 hectares, which indicates the level of details used for such a monitoring.

It is worth noting that, at the present moment, new procedures for image analysis are in development, totally on a digital basis. With this, specialists can analyze TM/LANSAT digital data and monitor complex areas in terms of deforestation, using image segmentation algorithms, identifying segments according to thresholds previously established as a function of the complexity of the area, and then after, applying a classification algorithm based on statistical similarity (Fidalgo *et al.*, 1994). In the procedure sequence, the result of the classification may compose, just like a digital image, one more plan of the Amazonia Data Bank, allowing to avoid an intermediary human/machine phase, which should be the digitalization during the visual phase. An alternative possibility, which is being tested, is the use of a scanner, an adequate and difficult preparation of the cartographic base being already necessary, to allow understand the series of minor dimension and form classes contained in it.

With the support of the IBM Scientific Center, Rio de Janeiro, the segmentation technique and following identification of segments by specialists in this matter, are being used to train neural networks and develop new classifiers, based on fuzzy logic, with the purpose to make the mapping of deforested area in Amazonia easier, within a satisfactory confidence interval (Barbosa et al. 1993; Machado et al. 1994). Experiments have been done in pilot areas in the Pará State, namely in the regions of Tucuruí, Altamira and in the core area of the Bragantina zone. Spectral and textural characteristics of forest segments, natural vegetation regrowth (different ages), agriculture and pasture areas which are being used to train the suggested classifiers.

It was observed during the monitoring of the amazonian forest ecosystem that one of the forms of disturbance is the construction of large dams (hydroelectric power plants), which causes heavy loss of forest biomass by the formation of artificial lakes. Landsat/TM images were used to study the extension of lakes, for land use dynamics analysis. Experimental research was developed to study the correlation between aerial phytomass, dendrometric parameters and spectral values of high and low land, which exist in areas to be flooded during the formation of lakes (Zerbini and Santos, 1993). This was done in order to stratify and evaluate the forestry capacity of the whole area and possibly to support an exploration project.

With high resolution satellite data (LANDSAT, ERS-1...), it is possible to distinguish the precise boundaries of the different types of vegetation which shows considerable diversity of flora, according to the local geographical conditions, types of soil and amount of rainfall. It is also possible to determine the deforesting level in tropical regions. Within a synoptic vision, the stratification of the types of vegetal cover versus its phenological conditions may be better studied with high time resolution satellites, as it is the case for NOAA/AVHRR, with 1.1 km2 spatial resolution in LAC (Local Area Coverage) format. As an example, let us quote Pardi et al. (1994), who used multitemporal data of NOAA/AVHRR to analyze seasonal change of the vegetation in areas of boundary forest/savanna woodland (Figure 2), which present several levels of disturbance. This kind of study was realized with AVHRR data in GAC (Global Area Coverage) format, with 4 km2 downgraded resolution. The detection of the variations of spectral patterns within these images is directly related to the foliar area index and to the radiation active for photosynthesis, associated to the climatic variation of the region during the year.

The advantage of the multitemporality of NOAA/AVHRR data including the capability of daily image acquisition, which difficults storage (large volume of information), counterbalance its low spatial resolution, even with LAC format (1.1 km2). However this does not prevent from using these data to monitor deforested area (Nelson and Holben, 1986) and even to identify fire points, maintaining a synoptic view of the region. In this case, the user of the information does not have to worry about the result significance in the mapped area, but he will have the adequate spatial location where a tropical forest conversion process is happening.

EXPERIENCE WITH SAR DATA FOR THE STUDY OF FOREST COVER

Within the context of the use of more adequate spatial resolution for forest conversion surveys, and considering the high percentage of cloud cover in determined areas of the Amazonia, it turns out to be necessary to verify the capability of SAR (Synthetic Aperture Radar) data. The SAREX'92 mission, within the Brazil-Canada Cooperation Project, with ESA (European Space Agency) financial support, was used to acquire knowledge on sensors which operate in the microwave region and, by the way , to support the management of natural resources in tropical forest region (Kux et al., 1993). A practical example which may be presented is the use of airborne radar (campaign SAR-580) in C band, with HH and VV polarization, simulating RADARSAT image. With the use of these geometrically and radiometrically corrected images SAR, it is possible to detect in the amazonian environment the forest cover types, deforested areas for use as pasture/extensive agriculture and subsistence, biomass burning areas and areas in process of vegetal cover regeneration.

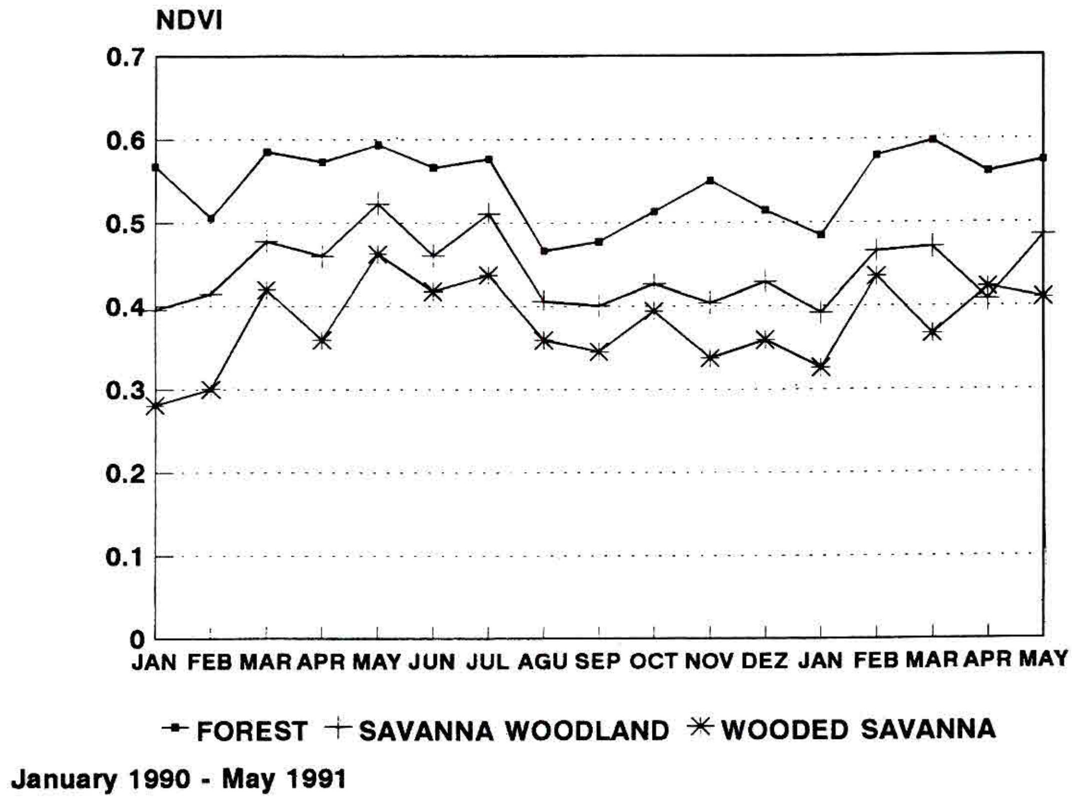

Fig. 2 — Monthly mean NDVI values of vegetation cover in the transition areas of forest/savanna. From: Pardi et al. (1994).

Deforested areas for agriculture and cattle-raising are clearly visible on SAR images due to their regular geometry and almost smooth texture, in contrast with the rough texture of primary forest canopy. C band SAR data, with VV polarization are indeed recommended to discriminate between pasture area and these in **initial phase** of natural regrowth. The deforested and abandoned areas, nowadays considered as **intermediary phase** in successive processes of the vegetation show a higher roughness than these in initial stage.

The experience acquired with SAR data and more recently with ERS-1 images in pilot areas of the amazonian region allows to evidence, in a general way, potentiality for:

a) an understanding of the annual dynamics of floods, as an essential information for the planning of several regions from the point of view of rational land use compatible with biodiversity conservation;

b) an estimation of the humidity in deforested areas, as a mean to evaluate the influence of this disturbance process at large scale, evaluating infiltration and evaporation levels in the water cycle of the region;

Among the pilot areas under study, "transects" in the region of Rio Branco-Sena Madureira (Acre) and in the National Forest of Tapajós (Pará), where is made an attempt to verify, by using ERS-1/SAR data, the structure of covariance between spectral bands and which are the statistical models that best fit to forest texture (as discriminating attributes among classes) and to the levels of deforestation and vegetal cover regeneration.

A better understanding of the identification of natural regeneration levels in deforested abandoned areas is obtained through the use of an integrated composition of Landsat/TM with SAR data, considering, according to Santos et al. (1994), the transformation IHS (Intensity/Hue/Saturation) in the treatment of such data, mixing the multispectral information of the optical sensor with the textural information of the microwave band sensor.

FINAL CONSIDERATIONS

Within a wide vision and analysis the problem of monitoring the amazonian forest ecosystem, one may make use of monthly "vegetation index" images built with NOAA/AVHRR data, which turns possible the follow-up of active for photosynthesis phytomass change, those associated to conditions of soil water content variability, and/or those associated to deforestation practice. Furthermore, within an integration of knowledge, with high resolution sensors (LANDSAT, ERS-1,...), it is possible to study other subjects on tropical forest, analyzing with more details, in the images, the process of deforestation, biomass burning, agriculture use and abandon of land and consequent beginning of natural regeneration, making possible a more precise estimation of area and greater capability of georeferentiation of the identified phenomenon.

This document clearly emphasizes the possibility to monitor tropical forest ecosystems by using remote sensing data. An evolution in the development of Earth resource sensors/satellites and in the techniques for extracting information are showing that the scientific community who works with remote sensing is on the right way to support part of the research in ecology and biodiversity, such as:

— development of standardized procedures to evaluate the quality, quantity and focus of biological inventories of tropical forest cover;

— current monitoring with regard to ecological changes as a results of land use;

— promotion of a practical and technologically feasible methodology to monitor the forest ecosystem, available at relative low cost.

It is hoped that natural resource scientists with considerable experience in conducting field work in the Amazon region may use satellite imagery for the inventory and monitoring of tropical forest ecosystem.

The aspects already analyzed represent a general view on the use of orbital remote sensing, dealing with the present monitoring of Amazonia. It is important to say that the methodology used up to now is under transfer to agencies/institute which study Amazonia resources, such as EMBRAPA/CPATU, MPEG/CNPq, FUNTAC, INPA, SUDAM, IBAMA, among others. The technological capability in this area, where the preoccupation is monitoring forest resources of the country, was widely practiced, extending also research and applications to other domains such as "pantanal", "caatinga", savanna as a mean to give support to agencies which are responsible for the management and administration of actions in these ecosystems.

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QUESTIONS

Question (1) – *I would like to know the total area of the devastation in Amazon.*

Second Question – *If there is some correlation between the devastation, the deforestation of the Amazon and some diseases... I mean, if you can follow by satellite photos, the devastation of the forest and connect to the existence of malaria in some region?*

Santos – OK. Well , my English is not very good. I have not fluency in English. I would like to respond in Portugues if Dr. Affonso helps me with this. A primeira questão é que nos levantamentos em que foram colocados números e que foram colocados na Science através das publicações do grupo de trabalho do Jimmy Tucker da NASA, há uma variação de números em função do que é considerado como cobertura florestal ou não. Os números que o INPE, que o nosso grupo de trabalho executa em termos de desflorestamento, estão relacionados a toda alteração em áreas de cobertura florestal; não estão incluídas aí as feições de Cerrado. Por exemplo, nós temos o Cerradão que tem fisionomia florestal, então ele está colocado aí dentro. Somente para responder um pouquinho mais, me permita: "...the following physionomic units are being considered: dense and open tropical ambrophilous forests, tropical seasonal forests woodland savanna, oligotrophic woodland (campinarana arbórea, por exemplo está incluída), and pioneer formations with fluviomarine influence ..." Os manguezais que nós temos, que têm uma estrutura de porte arbóreo, também estão incluídos. Então, toda essa variabilidade em termos do que nós definimos como desmatamento em áreas de cobertura florestal, eles não estão fazendo, no momento, no mesmo ritmo. Isto não implica que há um contato da equipe do Jimmy Tucker, da NASA conosco, para que a gente possa acertar esses números. Mas a diferenciação não é tão grande, que possa influenciar tomada de medidas com relação a futuras emissões de carbono ou reabsorção. Futuramente, quando a gente estiver começando a estudar a reabsorção do carbono face aos estudos de vegetação secundária que nós estamos iniciando agora, então poderemos abodar esse ponto. A outra questão era relacionada à antrofisação.

Questão (1) – *Se por exemplo, daqui a dois anos está chegando a malária em tal região e que está aumentando naquele sentido com o desflorestamento, qual é a correlação nesse sentido?*

Santos – A partir das informações que nós temos, e que estamos tentando executar em termos de um sistema de informação geográfica, onde voce possa examinar o posicionamento geográfico do desflorestamento ao longo dos vários anos por cartas MIR (que são as cartographic bases), eu acho que voce pode fazer um estudo nesse sentido. A direção do desflorestamento está indo num determinado sentido se voce, logicamente com o seu conhecimento nessa área, puder trabalhar os dados e analisá-los. Eu não gostaria de usar a palavra "manipular" os dados porque tem outro sentido. Mas são usados os dados.

Questão (1) – *Em comparação com as imagens, quais os outros esforços necessários?*

Santos – O grupo que está trabalhando com radares está iniciando o trabalho para termos informações a nível orbital, quer dizer, nós estamos trabalhando um radar colocado a nível de aeronave, e é necessário realmente termos o conhecimento de campo.

Para o trabalho de levantamento com o LANDSAT, nós já estamos muito avançados em termos de conhecimento. Agora o problema é você entender a informação vinda do radar. Por exemplo, nós estivemos agora realizando um trabalho no Acre junto com o Dr. Manfred, que é da DLR alemã. Ele trouxe as informações ligadas a outros tipos de sensores com radares, e nós estamos trabalhando essa informação. Então é um trabalho de paciência, mas o radar a nível orbital é fundamental. Ele tem uma importância muito grande, porque existem determinadas áreas da Amazônia que você não dispõe de informação, devido a alta cobertura de nuvens. Eu teria algumas outras informações mas o tempo é realmente curto; a gente não coloca toda a informação na discussão. Me permita fazer mais esta observação. Por exemplo, algo muito importante é o mapeamento e o conhecimento da dinâmica das áreas de inundação. Então o radar é importantíssimo. A outra questão diz respeito a você poder determinar a umidade das áreas desflorestadas através de uma relação com dados de radar. Inclusive, você pode verificar a influência desta umidade em função das áreas desflorestadas e estender isso a outras áreas.

Questão (1) – *O LANDSAT é bastante útil?*

Santos – Por ora sim, desde que ele se matenha lá em cima.

Questão (2) – *João, eu queria fazer um comentário em relação ao termo "Amazônia Legal" que você colocou. Realmente isso traz uma quantidade enorme de confusões porque a Amazônia Legal inclui por exemplo todo o estado de Tocantins, que tem 90% de área de Cerrado. Então todos esses números consideram os ambientes como ecossistemas diferenciados, apenas porque, do ponto de vista geográfico ou econômico, interessa separar como Amazônia Legal. Isso traz uma confusão enorme, não só no Brasil, como na literatura internacional. Eu gostaria que você esclarecesse para gente como é que realmente vocês processam os números que voces têm; se eles se referem exatamente à floresta ou se são de desmatamento; ou se incluem essas áreas dentro do ecossistema Cerrado, também com inclusões de mata.*

Santos – A idéia mais importante, veja bem que eu não estou discutindo inclusive porcetagem, exatamente porque o número de área desmatada sobre o número da Amazônia Legal, que é algo da ordem dos cinco milhões, eu não estou usando. Inclusive foi um alerta que eu fiz. Nós estamos trabalhando é toda a área de fisionomia florestal, onde nós temos algum desmatamento. Isso inclui dentro do próprio estado de Tocantins áreas que têm uma cobertura florestal. E isso também está sendo embutido lá dentro. Então tudo que passar dentro da Amazônia Legal, um limite que alguém definiu em épocas passadas, onde tenha uma cobertura florestal e tenha uma antrofização, nós estamos considerando. Veja bem, nós temos algumas feições que são de Cerrado, que não tem fisionomia florestal; ela automaticamente está fora. Tanto é que eu não estou estimando a taxa em função de um percentual; em função da área da Amazônia como um todo. Se eu fizesse isso hoje oficiosamente, eu diria para você o seguinte: eu não posso dividir o número de áreas desflorestadas por cinco milhões, mas talvez, se eu dividisse por tres milhões e oitocentos, tres milhões e novecentos, eu teria a área de vegetação digamos, de cobertura florestal, dentro dessa grande área da "Amazônia Legal".