CHARACTERIZING LAND USE DYNAMICS IN AMAZON USING MULTI-TEMPORAL IMAGERY AND SEGMENTATION TECHNIQUES

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ABSTRACT

This paper presents a technique for characterizing changes in land cover and land use based on the use of multitemporal Landsat Thematic Mapper (TM) imagery and a segmentation algorithm for image classification. Preliminary results of the processing of two TM scenes covering an area of important deforestation in the Brazilian State of Rondônia are discussed. The aims of this work are twofold: firstly, to develop a technique appropriate for detecting change in areas of the typical Rondônia "fish-bone" occupation, with a majority of small properties and some larger cattle-raising developments; secondly, to perform an analysis of land use dynamics in the region, with special emphasis on the characterization of areas of secondary vegetation.

RÉSUMÉ

Une technique pour la détection de changements de la végétation et de l'usage de la terre est presentée. Elle est basée sur l'utilisation de séries multitemporelles Landsat TM et d'un algorithme de segmentation d'images. Des résultats préliminaires obtenus pour deux passages TM dans l'État de Rondônia, dans l'Amazonie brésilienne, sont présentés; l'analyse de ces deux images a montré qu'une importante fraction des terres deboisées est abandonée, conduisant à la formation de régions de végétation secondaire.

INTRODUCTION

Despite some progress in mapping deforestation in the tropics, human-induced land cover and land use changes and the impacts of such changes are still poorly understood. For instance, the net emissions of greenhouse gases due to land use changes are estimated with high levels of uncertainty (Schimel *et al.* 1995); the part of deforested land that is abandoned, leading to the growth of secondary vegetation and the formation of a carbon sink, is not known; neither are well known the diversity of species of the secondary vegetation and the potential of use of such areas.

Satellite imagery has helped to improve the estimates of rates of deforestation, particularly for the Brazilian Amazon (Tardin *et al.* 1980; INPE 1992; Alves *et al.* 1992; Skole and Tucker 1993). However, the role of forest regrowth as a carbon sink is still poorly quantified (Schimel *et al.* 1995), despite a number of studies that use remotely sensed data to assess secondary vegetation regrowth (see, for example, Lucas *et al.* 1993; Alves & Skole, 1996). Secondary forests play an important rôle in diminishing the impacts of deforestation; beyond their role in fixing atmospheric CO_2, these forests help recover soils and nutrient cycling, and represent interest because of the usefulness of their species (Brown & Lugo 1990, Lisboa 1989).

One of the areas that suffered significant changes in the last decades is the state of Rondônia, Western Brazilian Amazon. Total deforested area in this state increased from 4,200 km^2 in 1978 to 34,600 km^2 in 1991 (INPE 1992). The average rate of deforestation during this period was of 2,340 $km^2 \cdot yr^{-1}$, the fourth highest state rate in Brazilian Amazonia, after the states of Pará (6,990 $km^2 \cdot yr^{-1}$), Mato Grosso (5,140 $km^2 \cdot yr^{-1}$) and Maranhão (2,450 $km^2 \cdot yr^{-1}$) (INPE 1992).

Pastures constitute the predominant type of land use in most of the State; according to FIBGE (1994), annual and perennial crops covered approximately 7,000 km^2 in the 1992/1993 period. Land development predominantly follows the typical Rondônia "fish-

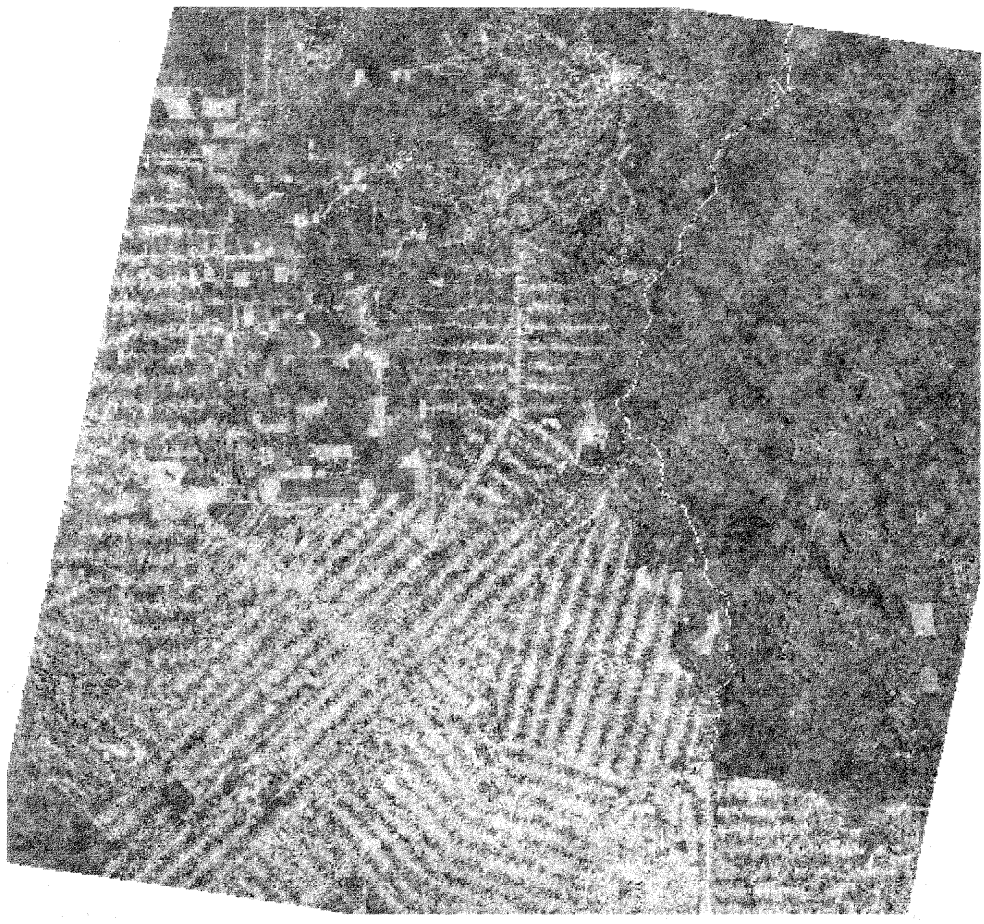

Figure 1 - Area of study (TM Band 5 for 07/15/94 is shown).
Brighter areas correspond to deforested areas. Dark grey areas are forest.

bone" pattern, with small properties (around 100 ha; 1 ha = 10^4 m^2) scattered along a network of roads; some areas of bigger cattle farms can also be found in the state, some of them with more than 10,000 ha. Part of the deforested area is abandoned in many regions of the State; Alves & Skole (1996) estimated that abandonment within an area of important recent occupation in Rondônia varied between 22% and 48% of the total deforested land between 1986 and 1992, while approximately 42% of abandoned areas existing in 1986 still remained in place after 6 years, to form older stages of secondary vegetation.

This paper presents a technique for characterizing changes in land cover and land use based on the use of multitemporal Landsat Thematic Mapper (TM) imagery and a segmentation algorithm for image classification. Preliminary results of the processing of two TM scenes covering an area of important deforestation in Rondônia are discussed. The aims of this work are twofold: firstly, to develop a technique appropriate for detecting changes in areas of the typical Rondônia "fish-bone" occupation, with a majority of small properties and some larger cattle-raising developments; secondly, to perform an analysis of land use dynamics in the region, with special emphasis on the characterization of areas of secondary vegetation.

AREA OF STUDY

The area of study corresponds to TM scene WRS-TM 231/067 (figure 1). It has an area of approximately 34,000 km^2 and is

delimited by coordinates 9° 27' S, 61° 08' W; 11° 04' S, 61° 29' W; 10° 50' S, 63° 08' W; and 9° 10' S, 62° 47' W. The BR-364 federal highway (Rondônia's most important road, linking the State capital to the Southern part of Brazil) traverses the area in the SE-NW direction; most of the developed properties are located along the secondary roads that derive from the BR-364 highway.

Following FIBGE (1992), the native vegetation in the region corresponds to the "*Floresta Estacional Semidecidual Submontana*" class. This tropical seasonal semi-deciduous forest covers areas with elevations ranging from 100 m to 600 m, and a 4 to 6-month dry season.

The majority of the properties have small areas (around 100 ha); some cattle-raising farms have 1,500 ha or more. A number of cacao and rubber plantations, funded by subsidies programs in the 1980's, have areas between 200 and 500 ha.

MATERIALS & METHODS

Satellite Data and Image Processing System

This study used Landsat Thematic Mapper bands 3, 4 and 5 for dates 07/15/94 and 08/05/90 (the area of work was defined considering five more images for years 1995, 1992, 1988, 1986 and 1985, that are being used for further work). TM data acquired and processed by INPE was provided in CDs.

The image processing system SPRING (Câmara *et al.* 1992) was used in this work. This INPE-developed software runs on UNIX workstations, and incorporates the functionalities mentioned in the following section.

Image Processing Procedure

The technique adopted in this work follows the procedure described by Alves *et al.* (1996) for image co-registration, segmentation and classification.

Six Landsat TM scenes (corresponding to the period 1985-1994) were initially read from the CDs. The 1994 image was geo-referenced using control points acquired with a Global Positioning System device (GPS) during a May 1995 visit to the region; the remaining 5 scenes were co-registered to the 1994 scene and then resampled to 120 m resolution (an August 1995 scene was later introduced into the data base).

The co-registered data were processed as described by Alves *et al.* (1996) to assure that all three bands for each image have the same variance and then segmented using the region-growing algorithm described by Bins *et al.* (1996). The result of the segmentation algorithm consists of an image of labeled regions that is subsequently classified by means of a region-oriented unsupervised classifier.

The segmentation method allows the user to define the minimum size of the areas and a minimum distance in digital levels for region growing. The un-supervised clustering algorithm classifies the regions, merging those that are closer than a specified threshold. After clustering, an interactive interpretation procedure is performed to assign clusters to one of the following classes:

- forest;
- use (agriculture and pasture);
- abandonment;
- water (rivers, reservoirs and ponds);
- shadows;
- undetermined (typically "noises" from different sources such as relief or forest texture)

Segmentation and classification errors are corrected using SPRING editing functions. Areas erroneously classified are corrected either by masking operations in the raster format or by editing polygon attributes after a raster-vector conversion. Areas missed by the segmentation procedure are hand-digitized at the end of the procedure.

After processing, the images for years 1990 and 1994 were analyzed using SPRING's raster analysis tools and the fractions of abandonment for each year and the areas classified as abandoned in both images were determined.

RESULTS AND DISCUSSION

Segmentation and Classification Results

As described by Alves *et al.* (1996), the segmentation results are visually more agreeable than pixel-by-pixel classifications (see figure 2). The classified images presented less edge effects and unclassified pixels than the pixel approach. As a result, the authors' experience indicates that complete classifications (including corrections) can be performed in an easier and more satisfactory way than pixel-based classifiers.

The adopted unsupervised classifier presented reasonable results for the initial discrimination of forest, use (agriculture and pastures) and abandonment. This can be partially explained by the relatively high contrast among these classes on TM bands 3, 4 and 5, that leads to good segmentation and classification results. The results, however, did not differentiate abandonment from some perennial plantations, like cacao and rubber, occurring in the region; it can be noted that the authors are not certain, at the

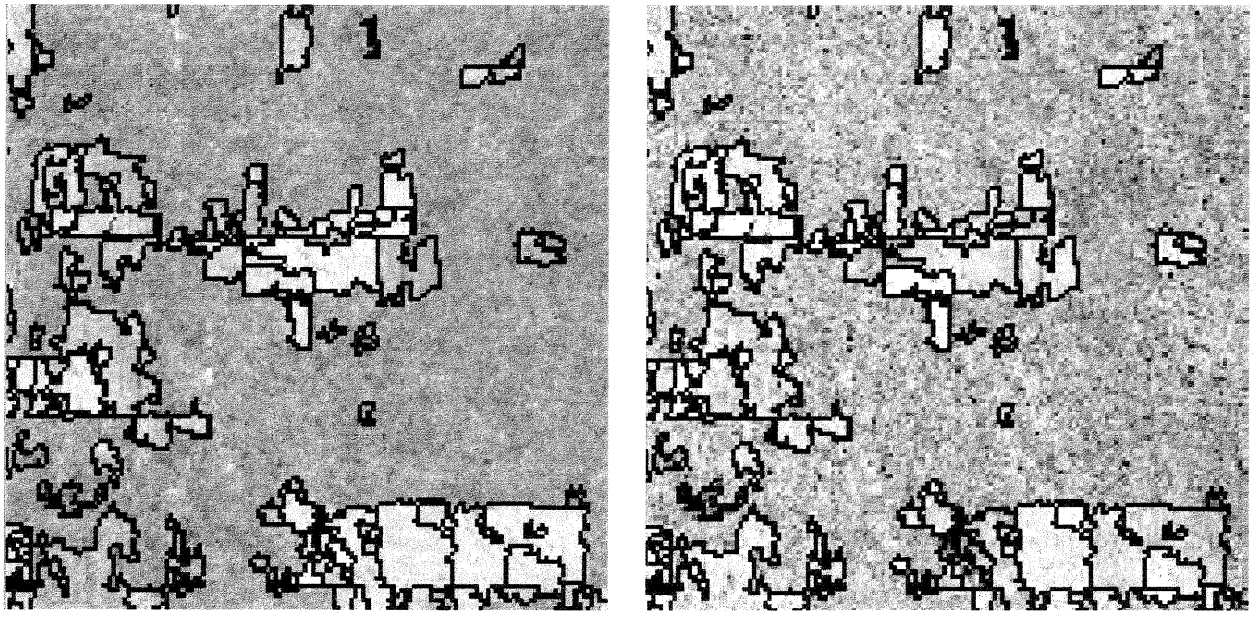

Figure 2 - Results of the segmentation algorithm shown for TM bands 5 (left) and 4 (right)

time of this writing, that these categories could be easily differentiated using TM data.

A more detailed discussion of the segmentation and classification results considering the specific land use practices adopted in the region is presented in the following sections. Without consideration to region-specific information, a few more characteristics of the technique adopted could be mentioned:

- the segmented images typically present clearly delineated areas, with relatively few edge effects; however, the algorithm can "miss" areas characterized by texture without continuous, clear edges (e.g. some areas of abandonment in the middle of forest); at the same time, it can generate erroneous segments in the middle of areas of forest because of shade and other effects;
- minimum area size and edge-threshold values are controlled by the user and the adequate definition of these parameters can minimize the effects described above; however, it is frequently difficult to establish the "ideal" values for one entire image, because of variations in terrain, vegetation characteristics, land use, etc.; the possibility of definition of different values for different parts of an image or an adaptive approach to calculate those values automatically could help to reduce the volume of corrections;
- the region-oriented classifier produces the merging of "similar" neighboring segments; this procedure has the positive effect of reducing the number of segments but some classification errors are made more difficult to correct; conserving the richness of detail of the segmented images could be used by more elaborate editing functionalities and reduce the time required for corrections.

Finally, it can be noticed that although the work produced at the 120-meter resolution lacks the detail of the original TM 30-meter resolution, experience has shown that they present less segmentation and classification errors due to relief, image texture and other effects. These results can be used as a reference or mask for more detailed work at the 30-meter resolution.

Forest Clearing and Land Use Practices in the Region

Most forest clearing in the area is made by two different techniques: clear-cut (all trees are cut) or the "quebradão" practice (many large trees are left standing, to reduce clearing costs and to maintain part of the vegetation). Clear-cut areas can be easily identified on TM images for longer periods of time, even if they are abandoned. Areas of "quebradão", however, can present a more vigorous regeneration; the authors found evidence that, in some cases, they can be confounded with forest just two or three years after the clearing.

Another peculiarity of the region is that land can be cleared to assert ownership or to raise property value, without maintaining the property productive. Secondary vegetation in such areas is expected to regenerate faster than areas under heavier use (Uhl *et al.* 1988), and thus reach a forest-like aspect within shorter periods of time.

The use of multitemporal data can be valuable under these conditions. "Quebradão" areas can sometimes be identified,

particularly if there are satellite data available for the initial regeneration stages. Areas abandoned shortly after clearing can also be identified by multitemporal analysis. Differentiation of these practices can help to better understand the impacts of deforestation and, particularly, that of land use dynamics on the carbon cycle.

Characterization of Land Use Dynamics

Preliminary results of the processing of 1990 and the 1994 scenes show that secondary vegetation represents an important fraction of the total deforested area. Occurrence of abandonment was checked in part of the area during a field campaign in September 1995. Image classification results and the field campaign also confirmed that part of the abandoned areas is re-cleared and part continues in the abandonment state, leading to development of older stages of secondary vegetation.

These preliminary results are very likely to be the upper limits of the fraction of the abandonment. They do not differentiate between perennial cultures (particularly cacao and rubber) and abandonment, that the authors found in some areas. A more detailed survey of the region is needed and the potential of using TM data for discrimination of these categories has to be thoroughly evaluated to improve the classification results and to produce reliable figures of the fractions of land in use and abandonment.

One interesting characteristic observed in this study is that part of the area classified as abandoned in 1990 was classified as forest in 1994. This occurred partly because of segmentation and classification errors, but, also, because of the difficulties in discriminating between forest and older stages of secondary vegetation.

The approach described in this paper is being used by INPE researchers to study land cover/land use dynamics in Rondônia and in other regions of the Brazilian Amazon. The aims of these studies are to determine how deforestation and abandonment evolved in the regions over the last 10-20 years, and to evaluate some of the impacts of human occupation in the Amazon. The approach described in this paper has proven to be useful for these studies, and can contribute to improve the assessment of the causes and effects of deforestation in the Amazon.

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