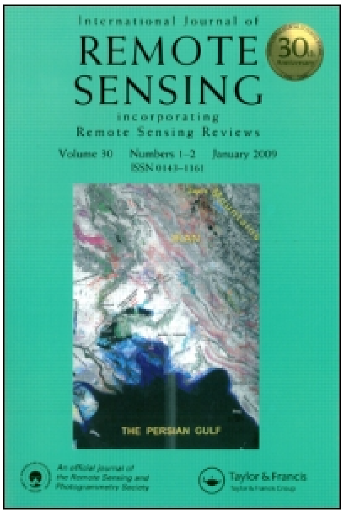

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Using shade fraction image segmentation to evaluate deforestation in Landsat Thematic Mapper images of the Amazon Region

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Abstract. Image segmentation based on the shade fraction of a Landsat TM image was effective in measuring the areal extent of Amazonian deforestation. The shade fraction image derived from spectral mixture models was related to the forest canopy structure. Dense tropical forests have a medium proportion of shade within their canopy while deforested areas (bare soil, pasture, and/or regrowth) have a comparatively small proportion. Comparison of image segmentation results with conventional techniques showed visual agreement. Even though additional tests are necessary to validate this approach for large areas, the technical soundness of the approach has been demonstrated.

1. Introduction

There is a need for continuous monitoring of deforestation in tropical forests due to its impact on climate, biodiversity and soil degradation. Currently used methods to estimate deforestation extent at regional scale are based on the visual interpretation of Landsat TM imagery (INPE 1996, Skole and Tucker 1993) or on limited digital classification based on pixel-by-pixel analysis without contextual information. Many ecological, hydrological and biogeochemical models require high spatial resolution and georeferenced digital data (geographical information system—GIS). This has lead to much visual analysis and hand-digitization. Even though visual interpretation has acceptable accuracy it is highly laborious and costly, especially in areas where small intricate fields such as the 'fish-bone' pattern of Rondônia predominate (INPE 1996).

Conventional digital analysis of Landsat TM data based on pixel-by-pixel classification is limited because it takes into account only the spectral variation of the scene, missing the potentially important contextual information of the objects. Fortunately, relatively new approaches using image segmentation have been quite promising for tropical deforestation estimation (Batista *et al.* 1994, Alves *et al.* 1996). However, this technique when applied directly to the original Landsat TM spectral information, demands significant computer time (Batista *et al.* 1994, and further investigation of this work).

Perhaps the most widely used technique to reduce the dimensionality of Landsat TM data, while still preserving most information required for adequate vegetation characterization is the normalized difference vegetation index (NDVI) proposed by Rouse *et al.* (1973). However, the NDVI has a major limitation for the characterisation of deforestation in the Amazon because young regenerating forests tend to have higher NDVI values than mature forest NDVI, while other deforestation classes,

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such as pastures or bare soils, have low NDVI values. Therefore, it is very difficult to design a simple deforestation classification algorithm using NDVI for the Amazon region. Fraction images based on spectral mixture analysis is another promising technique (Adams *et al*. 1995, Cross *et al*. 1991, Quarmby *et al*. 1992).

The shade fraction image has been found to be well correlated with vegetation canopy structure (Ranson and Daughtry 1987, Li and Strahler 1992, Jasinski 1990). Structure determines canopy shade content of land cover classes, for instance, undisturbed tropical forests, usually have medium shade content as opposed to deforestation classes such as bare soil, pastures, or regenerating forests with low shade content (Adams 1995).

We present an automated procedure to generate deforestation information including mapping and area extent estimations, integrated into a GIS database. This approach based on shade fraction image generated by a spectral mixture model, followed by region growing segmentation and a per-field unsupervised classification algorithm is operationally feasible for the Amazon. The validation of the procedure has been made by comparison with conventional techniques (INPE 1996) for a full Landsat TM scene in Rondônia, an area which is considered as a spatially complex as any scene in Amazônia.

2. Study site

Even though the methodological approach proposed in this Letter is envisioned to apply to the entire Amazon Basin, a complex scene with several small fields of the typical Rondônia 'fish-bone' pattern was selected (figure 1). This area covers approximately 34 000 km^2 and is dominated by dense tropical forest. Most of the deforested area is covered by grassy pastures in land holdings of 100 ha. In smaller proportions are perennial and annual crops, such as cocoa, coffee, rice and corn in fields with areas of 200 to 500 ha. Circa 22 to 48 per cent of previously deforested land has been abandoned and was covered by regenerating forests of different ages (Alves *et al*. 1996).

3. Data and procedure

Landsat TM images of bands 3, 4, and 5 from path/rows 231/67 (5 August, 1990—Rondônia) were used. The Landsat TM data were resampled to a pixel size of 60 m by 60 m resulting in a image size of 3326 pixels by 3072 lines, in order to reduce computer processing time. Charts at 1:250 000 (Rio Machadinho, FIBGE 1981 and Ji-Paraná, DSG 1982) were used for georeferencing the satellite images. The GIS software package SPRING (Câmara *et al*. 1992) with basic functions of image processing (including 'segmentation' and 'per-field clustering classifier'—ISOSEG) was used. Results of the PRODES Project (INPE 1996) for the same area were used for validation of the results of the proposed method.

3.1. *Shade fraction image*

There are several approaches to determine the fractional proportions of a multispectral image. The constrained least squares method was employed here using bands -3, -4, and -5 of the Landsat TM to generate the fraction images of vegetation, soil, and shade within the pixels.

The formulation of the mixture model based on the constrained least squares method is detailed in Shimabukuro and Smith (1991). The endmembers spectral signatures were collected directly from the Landsat TM images using representative

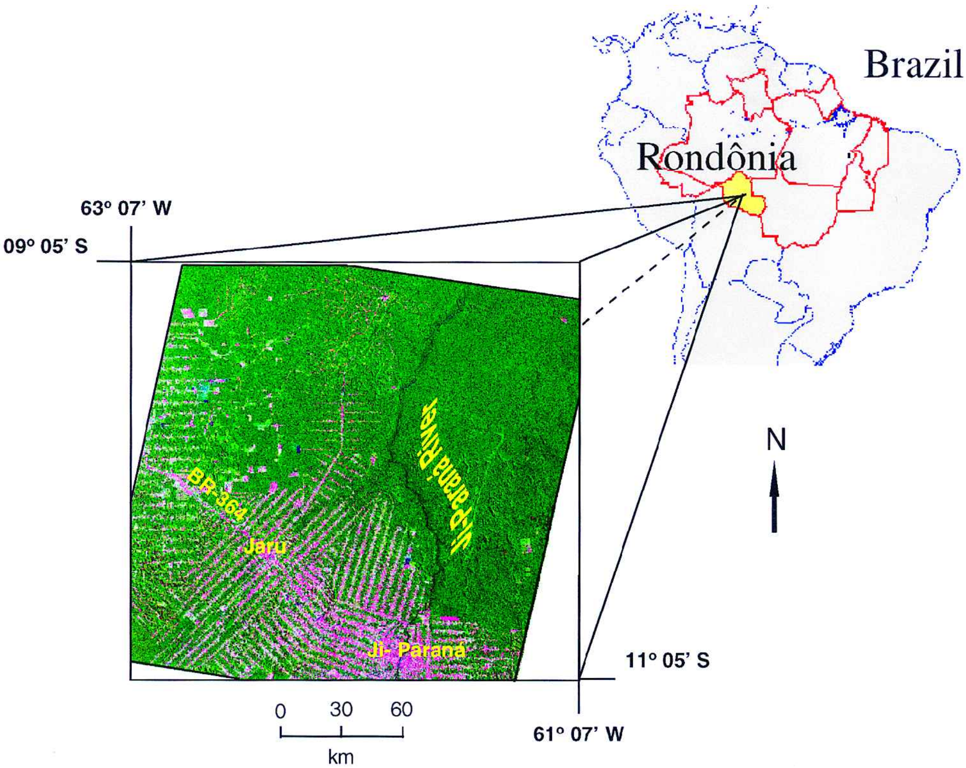

Figure 1. Georeferenced Landsat TM colour composite of bands -5, -4, and -3 (R, G, B) of the study site showing the 'fish-bone' land use pattern of deforestation in Rondônia along the BR-364 road.

targets of green vegetation, soil, and shade. This was done interactively until it was verified that the component signatures were an adequate representation of the mixture components of the area analysed and therefore the constraint equations were strictly true.

3.2. *Segmentation*

The procedure used for image segmentation was based on the 'region growing' algorithm where a region is a set of homogeneous pixels connected according to their properties (Zucker 1976). A detailed description of the segmentation procedure used can be found in Batista *et al.* (1994).

The segmentation algorithm was applied to the shade fraction image and the proportion, spatial and contextual attributes of the segments (regions) were acquired to be used in the classification procedure.

Two parameters have to be set by the analyst: (1) *similarity*: the Euclidean distance between the mean digital numbers (here shade proportion) of two regions under which two regions are grouped together; and (2) *area*: minimum area to be considered as a region, defined in number of pixels.

3.3. *Classification*

An unsupervised classification based on a clustering algorithm was applied to the segmented shade fraction image. Clustering techniques are largely known (Duda and Hart 1973). The algorithm used in this experiment, named ISOSEG (Bins *et al.* 1993) uses the covariance matrix and mean vector of the regions to estimate the centres of the classes. The analyst can define an acceptance threshold which is the maximum Mahalanobis distance that mean digital numbers (here shade proportion) of regions can be far from the centre of a class to be considered as belonging to that class.

The resulting clusters generated in the previous step are then identified by the analyst either as mature forest or deforestation classes. An accuracy assessment of this new alternative technique is possible by comparison with PRODES results (INPE 1996).

4. Results and discussion

After several experimental iterations of the segmentation algorithm applied to the shade image, the similarity and area thresholds were set to 8 and 25, respectively. They were set after a visual inspection guaranteed that all deforested classes were properly outlined. For the per-field unsupervised classification, the acceptance threshold was set to 99 per cent. As a result, there were only five classes generated by the ISOSEG classifier which made the analyst's job of associating these classes to deforestation classes very easy. Figure 2 summarizes the entire procedure to automatically generate deforestation estimations.

A comparison of the use of the shade image instead of the original Landsat TM bands (-3, -4, and -5) resulted in substantial saving in computer time: the process with the shade image took only 23 per cent (14·1 hours) of the required time to complete the process with the original bands (61·1 hours) using a SUN SPARCstation-20 with 96 Mbytes for RAM and 270 Mbytes of virtual memory. In addition, the analyst's editing job was much simplified. The generation of the shade image represented less than 2 per cent of the entire process. This same study site required 220 hours of an experienced delineators time to aggregate all deforestation areas from 1978 to 1990 into a single map.

The procedure reported in this Letter, similar to other techniques, requires editing after the digital analysis steps to eliminate some erroneous areas such as drainage pathways, roads, villages, rock outcrops and specular reflections and shadows from mountains and ridges (white areas in figure 2). These undetermined classes represented ca. 2 per cent in area of the full scene, requiring that the analysts label them without having to edit boundaries. Editing to include missed deforested areas were minimum. The reason for the reduction in the editing process is the excellent discrimination between mature forest and deforestation classes using the shade fraction image. By comparison, the conventional approach currently used in the PRODES project requires local adjustments done by manually overlaying the photo-interpretation maps to improve the geometry of the product. In complex areas such as in Rondônia the quality of the georeferencing is very poor due to the large number of small fields to be outlined. Distortions in several directions and misplacement of polygons boundaries are currently a source of error in the PRODES.

5. Conclusions

Pre-processing of the original Landsat TM bands to generate the shade fraction image allowed substantial reduction in the processing time for calculating a deforestation assessment. Results of the segmentation of the shade image followed by a per-field unsupervised classification suggest that this automated procedure for

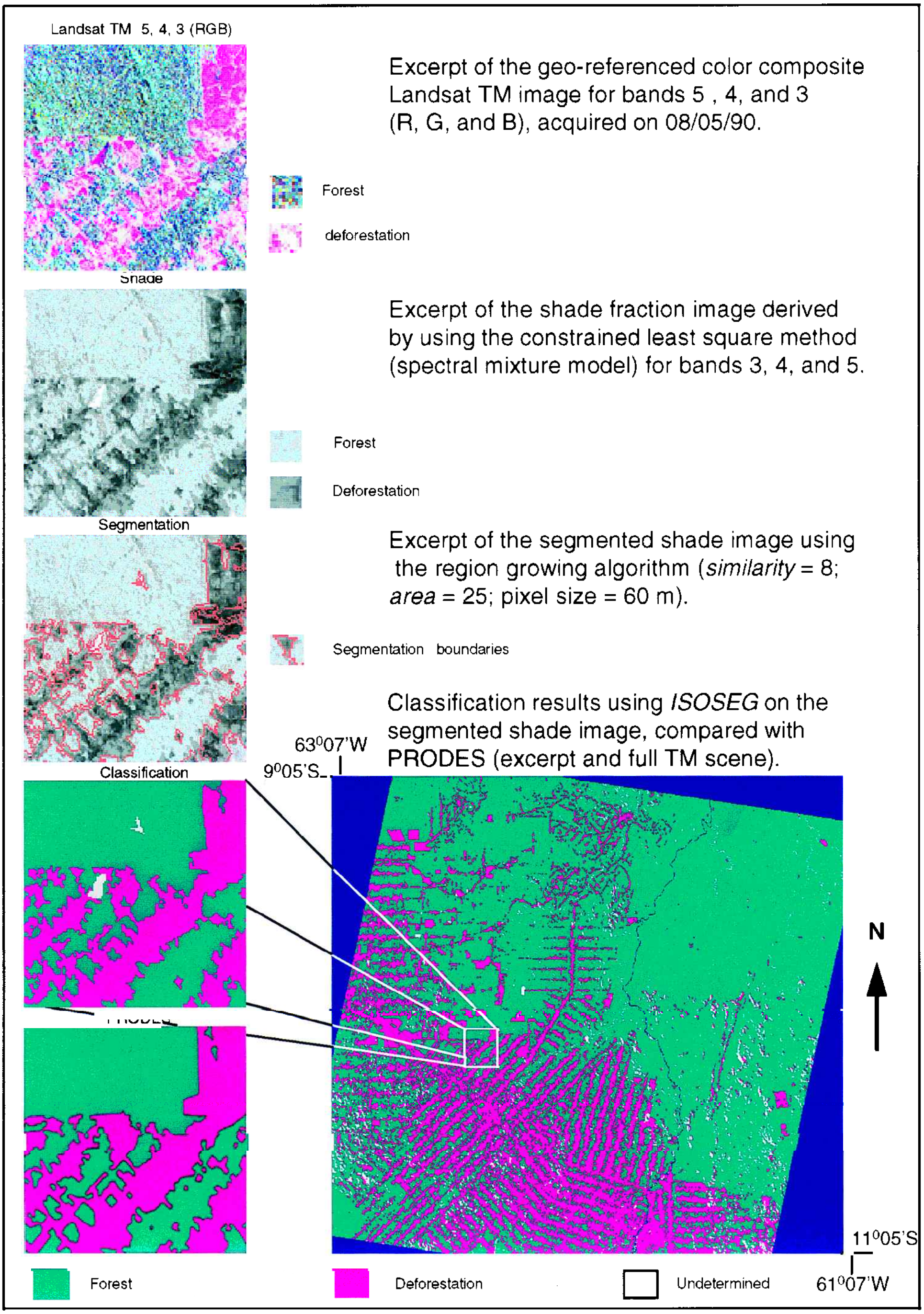

Figure 2. Steps and results of the automated deforestation estimation procedure applied to the full Landsat TM scene of Rondônia.

deforestation estimation is feasible and a sufficiently adequate technique especially for complex scenes of the Amazônia. The approach provides accurate results directly in a GIS format essential to model ecosystem land use and cover change. This is specially important for year-to-year monitoring of deforestation due to the limitation of the visual interpretation approach in complex areas.

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