BURNED AREA, RECURRENCE OF FIRES AND PERMANENCE OF BURNT SCARS IN SELECTED AREAS OF THE BRAZILIAN CERRADO USING TM-LANDSAT IMAGERY

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ABSTRACT:

A study was conducted in two selected areas of the Brazilian cerrado using Landsat imagery during a five years period (1996-2000), to address the following estimation issues: (1) burnt area using statistical sample techniques; (2) burnt scars permanence; and (3) recurrence of biomass burning. Regarding the burnt area estimates, a decrease of approximately 60% was observed during the period and was consistent in both study areas. It was also observed that the physiognomies most affected (wooded savannah and shrub savannah) remained the same throughout the period considered. A method was developed to allow a quantitative assessment to be made for the mean time of permanence of the burnt scars. The results indicated that there exists a large annual variation that also depends on the type of physiognomy affected. Regarding the recurrence (reincidence period), the most common pattern was characterized by the occurrence of only two burns in the period, spaced by two years time.

1. INTRODUCTION

The Brazilian cerrado (savannah) is the second largest bioma in South America, totaling approximately 3,000,000 km^2 (Eiten, 1994; Sato and Miranda, 1996). In Brazil, it covers almost 25% of the national territory (1,800,000 km^2), predominantly in the center-west region (Mato Grosso, Goias, Tocantins States). The cerrado vegetation is characterized by a gradient of woody biomass distributed in trees of at most 10 metres high and in a diversity of shrub formations. There are several definitions for the diverse vegetation physiognomies in the cerrado. In this paper, the definitions proposed by IBGE (1991) are adopted, as follows: *cerradão* (woodland), *campo cerrado* (wooded savannah), *parque de cerrado* (tree and/or shrub savannah), and *campo* (grassland savannah).

Biomass burning in the tropical savannah is a common practice, not only for the expansion of the agriculture but also, amongst others, to renew the vegetation in those areas which are used for cattle raising. It is well known that biomass burning activities are responsible for the emission of some greenhouses gases to the atmosphere, in particular carbon dioxide (approximately 90%). Other non-greenhouse gases, such as carbon monoxide, contributes to approximately 10%, and the others with roughly 1 to 2% (Levine et al, 1991). Grassland physiognomies of the cerrado are very resilient to fire and recover rapidly after burning, through regeneration. According to Andreae (1991) and Iacobellis et al. (1994), the increase of the atmospheric CO$_2$ concentration that results from the cerrado biomass burning is not significant, considering its re-incorporation in the vegetation, resulting from the regeneration process. However, this re-incorporation of carbon may occur after two years in the *parque de cerrado*, or even four years, in the *campo cerrado* (Miranda and Miranda, 2000). On the other hand, this re-absorption does not apply to other greenhouse gases that result from biomass burning, such as methane (CH$_4$) and nitrous oxide (N$_2$O). Hence, it is important to estimate the emissions of these gases which have a warming potential many times larger than CO$_2$.

The Intergovernmental Panel on Climate Change – IPCC provides, in its 1996 Revised Guidelines for Greenhouse Gas Inventory (IPCC, 1997), a methodology to estimate emissions of some greenhouse gases that result from biomass burning. However, one of the elements required is the total area affected by biomass burning, by type of vegetation physiognomy, a task which is not trivial for Brazil, in particular due to the following: (1) an extensive vegetation area to be monitored; (2) a long dry season (from June to October) proportional to fire occurrences; and (3) coarse resolution of the Brazilian vegetation maps (available only at regional scale (1:500 000). In addition, the burning efficiency, another element in the IPCC methodology, is a difficult parameter to assess.

Remote sensing systems are well known to provide systematic and complete coverage of the territory, thus being adequate to resolve issues (1) and (2) above, in a degree proportional to their spatial and temporal resolutions. Despite the regular acquisition of Landsat data in Brazil since mid 1970s, it is not simple to carry out an analysis of all Landsat imagery that covers the cerrado vegetation (estimated to be approximately 130), at every passage (16 days apart). In addition to the heavy workload to interpret and analyze the data, many images are affected (partially or totally) by clouds, thus impairing or making it impossible to assess the conditions on the ground. Krug and Santos (2001) have estimated the total area burnt in the cerrado using a sample of Landsat images and a number of different statistical methods. However, uncertainties associated with these estimates exist due to the fact that not all images acquired during the burning period are used for each path/row sampled, due to the quality of the images.

Despite the usefulness of satellite images, classification problems do exist, due to problems associated with the discrimination amongst thematic classes. For instance, fire scars in grassland physiognomies may not be discriminated in the satellite images, since they present similar spectral values to other classes (such as clouds, shadows, water bodies). Hence, it is important to understand the process associated with the permanence of the fire scars, to guide the sampling of the images to be used to estimate the annual area burnt in the cerrado. Permanence, in this context, is defined as the time lag between the appearance of a fire scar in a Landsat image and its posterior disappearance, resulting from vegetation regeneration.

Finally, the knowledge of the time elapsed between fires (recurrence) is important, for many reasons. For one, Gillon (1983) indicates that if grass fires occur infrequently, they are far less destructive, due to the amount of heat released, than if they take place annually. In addition, the recurrence of fires in the Brazilian cerrado influences ecosystem structure, nutrient dynamics, and is a significant source of atmospheric carbon, trace gases and particulates (Kauffman et al, 1994). According to Mueller-Dombois and Goldammer (1990), repeated burning destroys organic matter in the upper few centimeters of the mineral soil, nitrogen is removed in gaseous form, and repeated grass fires could result in skeletal soils highly impoverished of nutrients.

In view of the above, this paper sets up as objectives:

- To discriminate, in a sample of Landsat imagery, fire scars associated with the different types of the cerrado vegetation, and to quantify the corresponding areas;
- To study the recurrence of fires in the different types of physiognomies of the cerrado, during the period 1996-2000; and
- To estimate the permanence of the fire scars in the different physiognomies.

2. STUDY AREA

The areas encompassed by TM/Landsat image path/row 221/69 (henceforth referred to as Chapada dos Veadeiros site) and path/row 223/67 (herein referred to as Araguaia site) were selected for this study. Both areas are located in the core area of the Brazilian cerrado, and encompass areas of approximately 30,344 km^2 and 30,568 km^2, respectively.

According to RADAMBRASIL (1981), the most extensive vegetation cover in the Chapada dos Veadeiros site is *campo cerrado* (approximately 65%), followed by *parque de cerrado* (17%), forest (4%), *campo* (0.11%) and *cerradão* (0.02%). The dominant cover in the Araguaia site is *campo cerrado* (33%), followed by *parque de cerrado* (28%), *cerradão* (8%) and forest (8%). The physiognomy *campo* is not present in the Araguaia site. The remaining area is occupied by agriculture and water bodies.

3. MATERIALS AND METHODS

3.1 Materials

Sixty-three digital colour composite images of bands 3 (0.63-0.69ìm), 4 (0.76-0.90ìm) and 5 (1.55-1.75ìm) of TM/Landsat 5 or ETM+/Landsat 7 were used. At least one scene from each month of the dry period for each year investigated (1996 to 2000) was selected, based on the image quality and the presence of clouds. In addition to the satellite images, the study also included topographic charts, to guide the geo-referencing of the Landsat imagery, and vegetation maps, necessary to identify the distinct physiognomies affected by the burning, both at the scale 1:250,000.

3.2 Methods

3.2.1. Visual Interpretation of the Landsat Images: The identification of the fire scars was conducted through visual analysis of geo-referenced digital images, directly from the screen, to minimize the errors of inclusion that could result from digital classification. In the latter, areas which present a spectral signature similar to the fire scars, such as water bodies or cloud shadows, could otherwise be included under fire scars.

Initially, all the images associated with the first date of the dry period, for each year investigated, were analyzed and the fire scars mapped (those identifiable at the scale 1:50,000 in the Landsat images). Vectorial Information Layers (VIL) containing the boundaries of the fire scars were created for the first dates of each year, and layed over the images associated with the second dates. From the spectral-textural changes observed in the fire scars in the second date, the mapped fire scars from the first date were altered or deleted, according to the following criteria: (1) decrease in size of the fire scar, due to vegetation regeneration; (2) increase in size, resulting from new burns contiguous to the previously burnt areas; (3) elimination of the fire scar, when its signature could not be discriminated by the interpreter; (4) inclusion of new fire scars, not observed in the previous date. The result of this procedure was contrasted with the subsequent date, according to the criteria above, until the entire sequence of images was analyzed.

This process was carried out using SPRING 3.6 (Georeferenced Information Processing System) (Câmara *et al.*, 1996), generating at least one VIL for each month of the dry period. The resulting VILs were transformed into Matrix Information Layers (MILs) to allow algebraic operations to be carried out. These operations were necessary to estimate the annual fire recurrence, the total burned area and the permanence of fire scars. Each MIL consisted of a binary image where, for each pixel, a label "*Burned*" or "*Background*" was associated, depending on the condition of that pixel (burnt or not burnt).

3.2.2. Annual Area Burnt: The annual area burned was estimated by aggregating into a new MIL all the pixels classified as "*Burned*" in the MILs associated to any given year. Each one of the five MIL images (referred to as *aggregate image* 1996, 1997, 1998, 1999 and 2000), was cross-referenced with the vegetation maps, which were annually updated from the Landsat imagery. Hence, each pixel in the MIL image was associated to a vegetation physiognomy. This was done independently for Chapada dos Veadeiros and Araguaia sites.

3.2.3. Inter-annual Recurrence of Fires: The inter-annual recurrence of fires (1996 to 2000) was estimated for each site by aggregating into a new MIL all the pixels classified as "*Burned*" in at least one of the five aggregate images. Each pixel on the new MIL was associated to a 5-digit label (one for each year) using the symbol "B" if the pixel was labeled "Burned" in the aggregate image, or "G", otherwise. For example, a pixel labeled BBBBB in the new MIL indicated that the area corresponding to that pixel was burnt in 1997, 1998, 1999 and 2000; or BGBGG, indicating that the pixel was classified as

'Burned' in the aggregate image 1996 (AI 1996), 'Background' in the AI 1997, 'Burned' in AI 1998, and 'Background' in AIs 1999 and 2000. There are 32 possible combinations of 'Bs' or 'Gs' in a five-digit representation, indicating the status of any specific pixel in the aggregate images. From these 32 sequences, only 26 are of interest, since the sequence GGGGG is discarded (no fires), as well as the five sequences which do not characterize recurrence (presence of a single 'B' in the sequence, such as BGGGG). The 26 remaining sequences were cross-referenced with the vegetation maps, so that the recurrence area could be estimated for each type of vegetation physiognomy.

3.2.4. Permanence of the Fire Scars: The permanence of the fire scars was defined, *a priori*, in periods of 16 days, corresponding to the revisit time of the TM/Landsat satellite. This definition implied in the elimination of year 1999 from the analysis, since in this year both TM or ETM images were included, and the time difference between acquisitions by Landsat 5 and 7 was only eight days. Theoretically, in order to cover the entire dry season (burning season), images acquired in times t+16, t+32, t+48, t+64, t+80, t+96, t+112, t+128, t+144 and t+160 (in days) should be available. However, during the period considered, only partial sequences were obtained, as indicated in Table 1.

Chapada dos Veadeiros site										
Year	Sequences of revisit (days)									
	16	32	48	64	80	96	112	128	144	160
1996	X		X			X	X			
1997	X	X		X		X		X		X
1998		X	X		X	X		X		
2000	X		X	X	X		X			
Araguaia site										
1996	X	X		X	X		X			
1997			X		X		X			X
1998	X	X		X	X		X			
2000	X	X	X	X	X			X		

Table 1. Availability of Landsat 5 imagery during the dry season.

The permanence of the fire scars was estimated on a pixel by pixel basis, by analyzing the spectral-textural variability of the fire scars along the dry season of each year. This was carried out by associating to each pixel in every image of a given year, the label "*Burned*" (B) or "*Background*" (G), if the interpreter could still identify the fire scar in the image, or not, respectively. In a year where five images were available, the sequence BBGGG associated to a given pixel would indicate that the fire scar was spectrally visible for a period of two consecutive dates, and spectrally not discernible in the last three acquisition dates. Areas covered by clouds and shadows were disregarded from the analysis, as well as those associated to 'B' in the first date of the sequence.

This was due to the impossibility to determine the number of days between the occurrence of the fire and the satellite passage, thus creating uncertainties in the estimation. Hence, the observation of the fire scars started from the second image available (*reference date*).

4. RESULTS AND DISCUSSION

4.1. Area Burnt

The estimates of the burnt area indicated, for both Chapada dos Veadeiros (CV) and Araguaia (A) sites, a systematic decrease from 1996 to 2000, from approximately 4,186 km^2 and 4,752 km^2 in 1996 to 1,327 km^2 and 2,138 km^2 in 2000, respectively. The only exception to this pattern was the year 1998, with increases of 214% and 246% in relation to 1997, for CV and A sites, respectively. This increase may be due to the fact that 1998 was possibly the warmest year of the decade (IPCC, 2001), resulting in diminished soil moisture and water content in the vegetation. In the CV site, the physiognomies most affected by biomass burning were the *campo cerrado* and *parque de cerrado* (which correspond to approximately 81% of this study area, being responsible for approximately 98% of the total area burned). These physiognomies were also the most affected ones in A site, covering approximately 61% of the area of this site and concentrating approximately 95% of the total area burned.

4.2. Recurrence of Burns

Approximately 16% and 18% (4,703 km^2 and 5,373 km^2) of the total area of the cerrado, in the CV and A sites, were affected by the recurrence of fires from 1996 to 2000, respectively. The sequences characterized by a single recurrence, independently of the year of the fire, were the most common (77% in CV site and 62% in A site) and in both areas, the single recurrence, spaced by one year (i.e., sequences of the type BGBGG, GBGBG or GGBGB), represented approximately 68% in CV site and 59% in A site. The second most frequent type of sequence was that characterized by two recurrences (19% in CV site and 31% in A site). It is interesting to note that in CV site, approximately 8% of this type of recurrence was sequential (i.e., BBBGG, GBBBG, or GGBBB), whereas in A site, the most frequent sequence (approximately 12%) was characterized by intercalated burns (i.e., BGBGB). The sequence characterized by four recurrences (BBBBB) was very minor (0.35% in CV site and 0.79% in A site).

4.3. Mean Permanence of the Fire Scars

The analysis of the data indicated that the mean permanence of the burnt scars is subject to significant annual variations. For the Chapada dos Veadeiros, the mean permanence for the period 1996-1997-1998-2000 were 79, 55, 102 and 47 days, respectively, whereas the corresponding data for Araguaia were 64, 96, 82 and 57 days. Regardless of the differences (in absolute terms) of the mean permanence for each year in the period analyzed, the physiognomy **campo** was the one that consistently presented the longest mean permanence of the fire scars, followed by the *parque de cerrado* and *campo cerrado.*

5. CONCLUSIONS

Although this study was carried out in two specific areas of the Brazilian cerrado, it introduces a methodology that can be applied to larger areas, being also adequate for use with data from other types of sensors, such as the MODIS. In this case, small burnt areas may not be detected due to the coarser spatial resolution of the MODIS (250 metres) relative to the TM (30 metres). The range of mean permanence from one year to another in a same area indicates the difficulties to consistently characterize the permanence of the fire scars.

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