The Cerrado vegetation fire susceptibility according to the distance from roads and previous fires

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Abstract

High incidence of fire of anthropic origin is frequent in the Cerrado —Brazilian Savannas—, especially in the dry season. In this paper, we assess the Cerrado vegetation fire susceptibility in relation to the ignition source considering that it has an anthropic origin. We analyzed the distance between the fire spots and two anthropic activity indicators: the road network and previous day fire spots. We analyzed data from the main road network of the study area and the location of fire spots detected in the channel 3 of the Advanced Very High Resolution Radiometer (AVHRR) on-board the NOAA-12 satellite. High incidence of vegetation fires is related to the proximity of the anthropic activities: 24% of the fire spots were observed in a 10 km wide zone along the main roads and 10 km around the previous day fire spots. The total area in a 10 km wide zone along the roads corresponded to 582,000 km^2, which is about 27% of the total Cerrado area. The total area in a 10 km around previous day fires was 33,000 km^2, which is about 2% of the total Cerrado area. The results demonstrated that the anthropic activity indicators used here can be utilized to assess the Cerrado vegetation fire susceptibility. Fire prevention actions based on data of fires that occurred during the previous day can be more effective, as these areas are smaller than the ones along the main roads and require less personnel and equipment to prevent future fires.

Keywords: Cerrado; savanna; fire; fire susceptibility; roads; spatial analysis; remote sensing.

1. Introduction

The fire, although being a natural event in the Cerrado—Brazilian savannas—, started to be used by the pre-Colombian men for hunting, war, vegetation management and area clearance (Anderson e Posey, 1985; Coutinho, 1990). At the present, causes for Cerrado anthropogenic ignitions are pasture regrowth and clearing areas for cultivation (Coutinho, 1990; 2000; Mistry, 1998a, 1998b). The estimated annual percentage of Cerrado burning is between 20% and 30% (Coutinho, 1990; França, 2000), with about 70% to 75% of the burned area occurs in the dry season (França, 2000). The high incidence of Cerrado burnings has been related to environmental damage which cause (i) biodiversity reduction; (ii) soil impoverishment, (iii) soil erosion (Mueller-Dumbois e Goldammer, 1990; Alho e Martins, 1995); (iv) local pollution; (v) regional climatic change; (vi) global climatic change caused by the greenhouse effect (Crutzen e Andreae, 1990; Mueller-Dumbois e Goldammer, 1990) and others.

Three simultaneous conditions are necessary for the fire vegetation: (a) favourable meteorological conditions, (b) availability of vegetal fuel and (c) existence of an ignition source. The rainy season in the Cerrado favours biomass growing and accumulation, while during the dry season most of the biomass, which is mainly composed by grasses, dries up (Oliveira, 1998; Ramos Neto, 2000). As already cited here, human is the main ignition source for the dry season fires (Coutinho, 1990; 2000; Mistry, 1998a; 1998b). According to Vasconcelos *et al*. (2001), the spatial pattern of the fires in Central Portugal was associated to the accessibility and presence of anthropic activities. The study has shown a significant relation between the fire location and the distance from the road network, urban and agricultural areas, with the ignition probability decreased when distance increased.

Recently, more importance has been given to the prevention of vegetation fire than to the suppression. It is easier to prevent or to early attack the fire than to tackle an established or propagating fire (Soares, 1985; Vasconcelos *et al*., 2001). The knowledge of the vegetation fire susceptibility makes possible the planning of preventive measures that lead to an optimized resources allocation in a better cost/benefit ratio (Soares, 1985).

Indexes can indicate the vegetation fire susceptibility. The old indexes estimate the vegetation humidity based on meteorological data such as precipitation, air temperature and humidity, wind, and solar radiation. Other indexes use also vegetation humidity collected in the field (Soares, 1985). Nowadays, these indexes are also based on estimates of vegetation humidity obtained from remote sensing data, generally with better spatial and temporal resolution. New indexes, in addition to the short-term variables related to vegetation humidity, also incorporate long-term variables such as: seasonal meteorological patterns; load and type of vegetal fuel; land cover and/or land use data including urban and agricultural areas and road network; elevation, slope and aspect of terrain; access restrictions; firebreaks; population density; spatial and temporal distribution of the fires. Furthermore, the advent of the Geographical Information

Systems (GIS) benefited greatly the indexes. These systems allow for the simultaneous utilization of different data with increased spatial and temporal resolutions (Pivello e Norton, 1996; Chuvieco et al., 1997; Ferraz e Vettorazzi, 1998, Vasconcelos et al., 2001).

This paper aims to evaluate the relationship between the Cerrado vegetation fire susceptibility and the proximity to the road network and fire spots occurring in previous day. The road network and the previous day fire spots are taken as indicators of anthropic activity. This research considers the probability of fire in the Cerrado as inversely proportional to the distance to the two anthropic activity indicators analyzed here. The fires are likely to occur near the roads as they provide the main access to the agricultural sites where fire is used as part of the current management practices. The previous Cerrado fire spots are indicators of sites and seasons that gather the three necessary conditions for fire: favourable meteorological conditions, availability of vegetal fuel and existence of an ignition source.

3. Materials and methods

3.1. Characterization of the study area

The study area includes the continuous part of the phytoecological region of the Cerrado defined as the 'Savanna' in the Vegetation Map of Brazil (Instituto Brasileiro de Geografia e Estatística [IBGE], 1993). The area also includes regions of 'Tropical Forest', 'Caatinga' and vegetation submitted to 'Ecological Tension' that indicate the contact between the Cerrado and other types of vegetation. The study area included both areas of natural vegetation and submitted to some kind of anthropic management. The total study area has about 2,200,000 km^2, covering about a quarter of the total Brazilian territorial area. The Cerrado can be found between 2°30'S to 26°00'S and 41°45' W to

62°00'W, covering the following Brazilian states: Distrito Federal, Goiás, Tocantins, Mato Grosso do Sul, Mato Grosso, Maranhão, Piauí, Minas Gerais, Bahia, São Paulo, Rondônia, Pará and Paraná (Fig. 1).

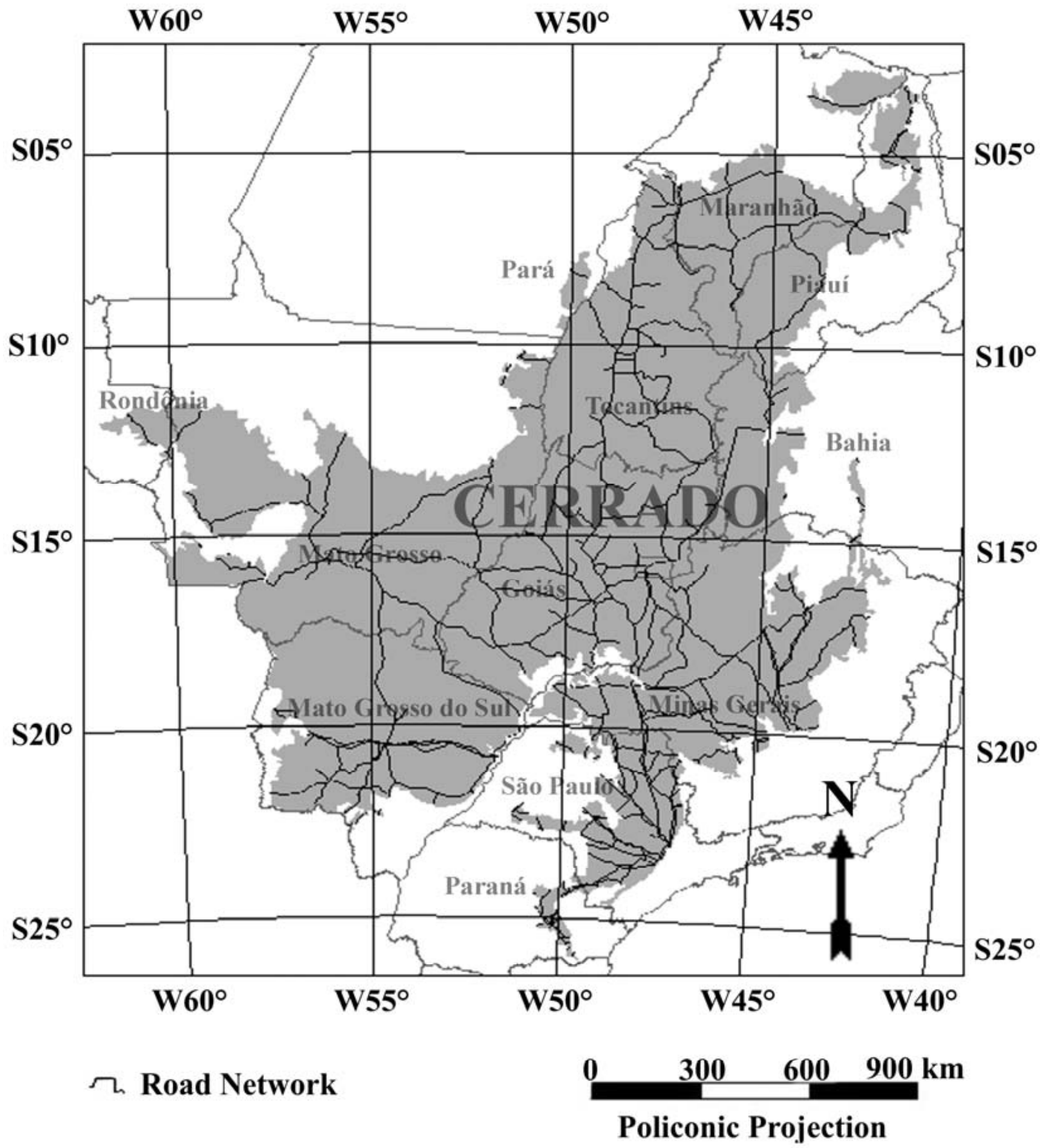


Fig. 1 – Cerrado study area measuring 2,200,000 km^2 including the main road network.

The natural vegetation of the Cerrado is cerrado lato sensu. It is characterized by a mosaic of physiognomies ranging from grassland, the campo limpo, through open scrublands, the campo sujo, campo-cerrado and cerrado, to woodland type, the *cerradão*. They are differentiated by the gradient of woody stratum over the herbaceous stratum that is generally formed by grasses (Coutinho, 1990, 2000; Ribeiro e Walter, 1998). However, extensive cattle ranching cover today around 60% of the total area of the Cerrado and intensive grain culture, mainly soybean, cover around 6%. The agricultural and urban expansion degraded about 55% to 65% of the total Cerrado area (Machado *et al.* 2004; Mantovani e Pereira, 1998).

The climate type in Cerrado region is Aw, characterized as tropical wet with strong rain seasonality and stable mean daily temperature (Dias, 1996). The annual mean precipitation is between 600 mm to 2000 mm, with 75% of the total Cerrado area subject to precipitation rates of about 1000 mm to 1600 mm (Assad e Evangelista, 1994). Only 5% to 10% of the rain occurs during the dry season from May to September (Castro *et al*., 1994). Daily mean temperatures in spring and summer range between 20°C to 30°C while in winter they range between 15°C to 24°C (Nimer e Brandão, 1989). The best condition for the drying and burning of the herbaceous stratum of the Cerrado occurs during the dry season.

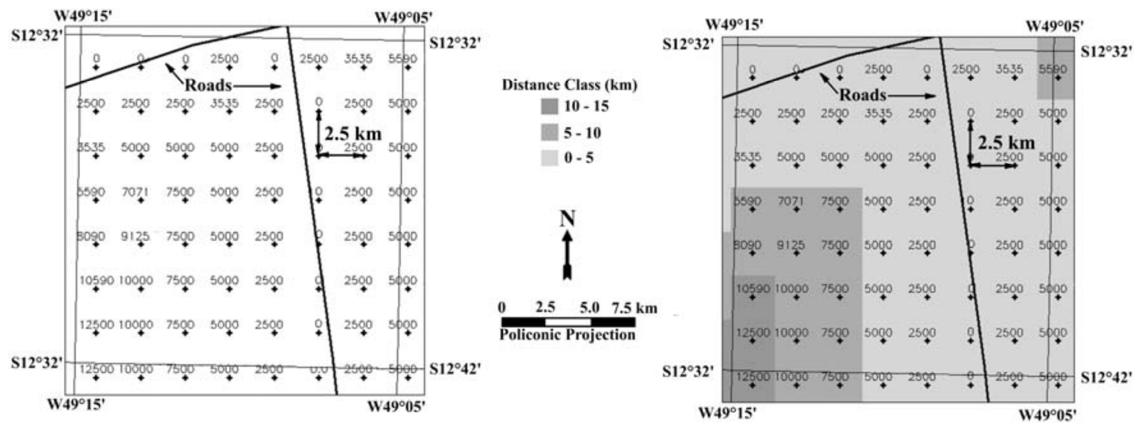
3.2. Materials

The geographical coordinates of the fire spots were taken from daily images of the channel 3 (3,7 µm thermal infrared) of the AVHRR on-board of the NOAA-12 satellite. The satellite afternoon passes (21h30 UTC) from May to October 1998 were used. The detection and mapping of fire spots was done at the Environmental Satellites Division (DSA) of National Space Research Institute (INPE) using the methodology described by Pereira (1987) and Pereira e Setzer (1993). The road network —roads and railroads— was digitally obtained from IBGE (1997). The data processing of this work were made using SPRING 3.5 software (Câmara *et al*., 1996).

3.3. Methods

3.3.1. Road network data processing

The input of the road network into the GIS allowed the generation of a regular numerical grid (Fig. 2a). The numerical regular grid is a numerical matrix where points are separated by a fixed distance called spatial resolution. The grid resolution used here was 2.5 km. The numerical value of a grid point corresponds to the shortest distance of this point to the road network. This procedure resulted in a grid of distance to the road network. A map of distance was generated using a GIS slicing technique in this grid. The slicing technique associates the numerical values of the grid to intervals (slices) corresponding to classes of distance to the road network (Fig. 2b). The following step was the computation of the area of each class.



a) b)

Fig. 2 – Detail of the: a) regular numerical grid with 2.5 km resolution where the values represent the shortest distance in meters of a grid point in relation to the road network; b) map of distance to the road network whose distance classes was generated from the grid which overlaid the map.

3.3.2. Fire spots data processing

Fire spots data from AVHRR´s channel 3 images were incorporated into the GIS and selected from two satellites passes every fortnight, covering the Cerrado region. These fire spots are referred in this text as **recent fires** (Table 1). After, fire spots originated one day before the recent fires were selected. These data are referred as **previous day fires** (Table 1). For instance, the fires of 8 May are recent fires while fires of 7 May are previous day fires.

Table 1 – Selected dates of recent and previous day fires occurring from May-October 1998.

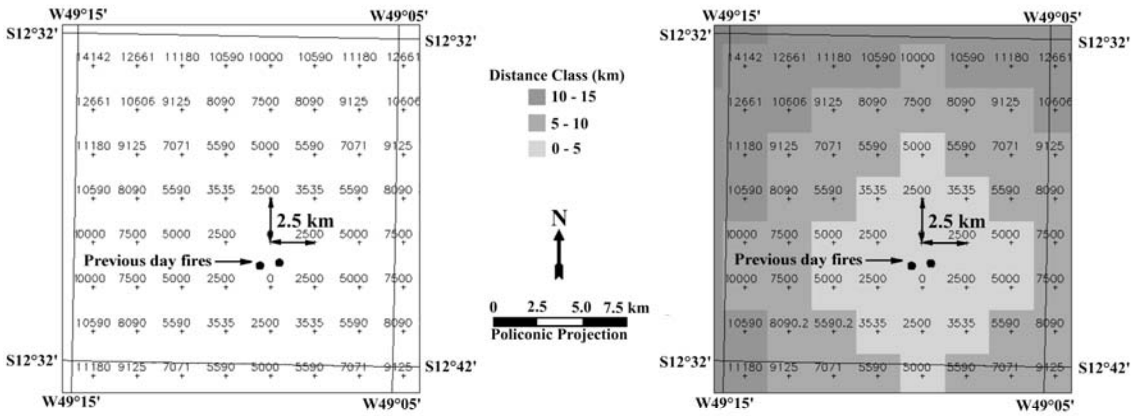
Month	Days - recent fires	Days - previous day fires
May	08, 13, 22, 26	07, 12, 21, 25
June	04, 09, 18, 22	03, 08, 17, 21, 30
July	01, 06,20, 29	05, 19, 28
August	03, 12, 16, 21	02, 11, 15, 20
September	03, 12, 17, 26	02, 11, 16, 25, 30
October	01, 05, 19, 23	04, 18, 22

Previous day fire data were used to generate regular distance grid at a 2.5 km resolution. The value of each grid point corresponded to the distance to the nearest fire spot (Fig. 3a). This procedure resulted in 24 grids of distance to the previous day fires. Each grid corresponds to a distinct date. The slicing technique applied to these grids generated 24 maps of distance to the previous day fires (Fig. 3b). The distance intervals used in the slicing were the same of the road network grid, resulting in the same distance classes. Following that, the area of each class in each date was computed. The

8

average area of each class over the period of study was also calculated.

The fire spots were considered as ground truth with respect to the incidence of Cerrado vegetation fires, indicating the areas and dates where and when the three conditions for the occurrence of fires in the Cerrado were satisfied.



a) b)

Fig. 3 – Detail of the: a) regular numerical grid with 2.5 km resolution based on the previous day fires from 20 August 1998 where the values represent the distance in meters of a grid point in relation to the nearest fire; b) map of distance to the previous day fires from 20 August 1998, whose distance classes was generated from the grid which overlaid the map.

3.3.3. Overlapping the recent fires with the distance maps

The number of recent fires in each distance class was computed for the 24 dates. This was made by overlapping the recent fire data with the distance maps. For the road network, overlapping was made between the map of distance to the road network and the recent fires (Fig. 4a). For the previous day fires, overlapping was made between the maps of distance to the previous day fire and the recent fires (Fig. 4b).

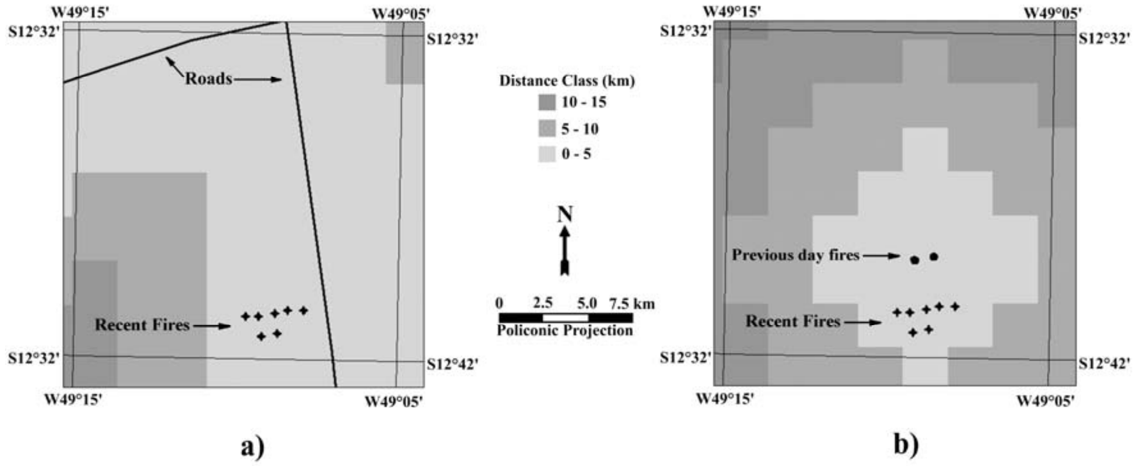


Fig. 4 – Detail of the: a) overlap of recent fires (21 August 1998) with the map of distance to road network; b) overlap of recent fires (21 August 1998) with map of distance to the previous day fires (20 August 1998).

4. Results and Discussion

4.1. Distance maps generation

The distance grids generated at a spatial resolution of 2.5 km were compatible with the 2 km accuracy for the location of fire spots. This implies that choosing a higher resolution would not result in higher accuracy for positioning the recent fires in the distance maps. Furthermore, that would increase the processing time to generate the grids and distance maps as well as the overlap of them with the recent fire data.

The application of the slicing technique in the GIS resulted in the map of distance to road network (Fig. 5) and in 24 maps of distance to previous day fires (Fig. 6). The classes of distance to road network and their respective areas are seen in Table 2. Table 3 shows the data for the previous day fires. Regarding the distance to the road network, the nearest classes had larger areas. Distant classes tended to have smaller areas. The results of the distance to the previous day fires, on the other hand, showed that the nearest classes were smaller, growing in size up to the 40-45 km class. That happened due to the geometry associated to the classes of distance to the anthropic activity indicators.

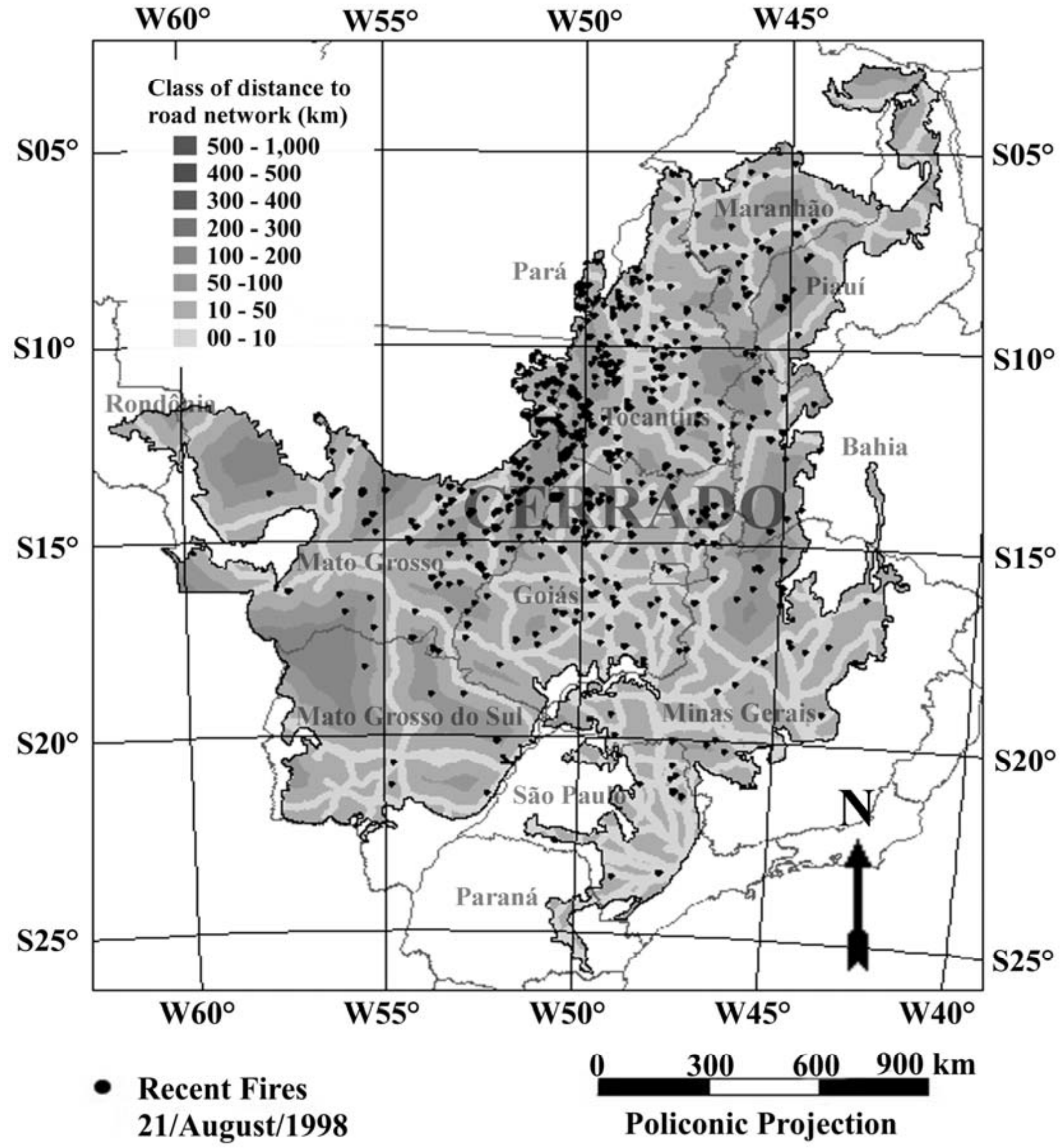


Fig. 5 – Map of distance to road network with recent fires (21 August 1998) in the Cerrado.

11

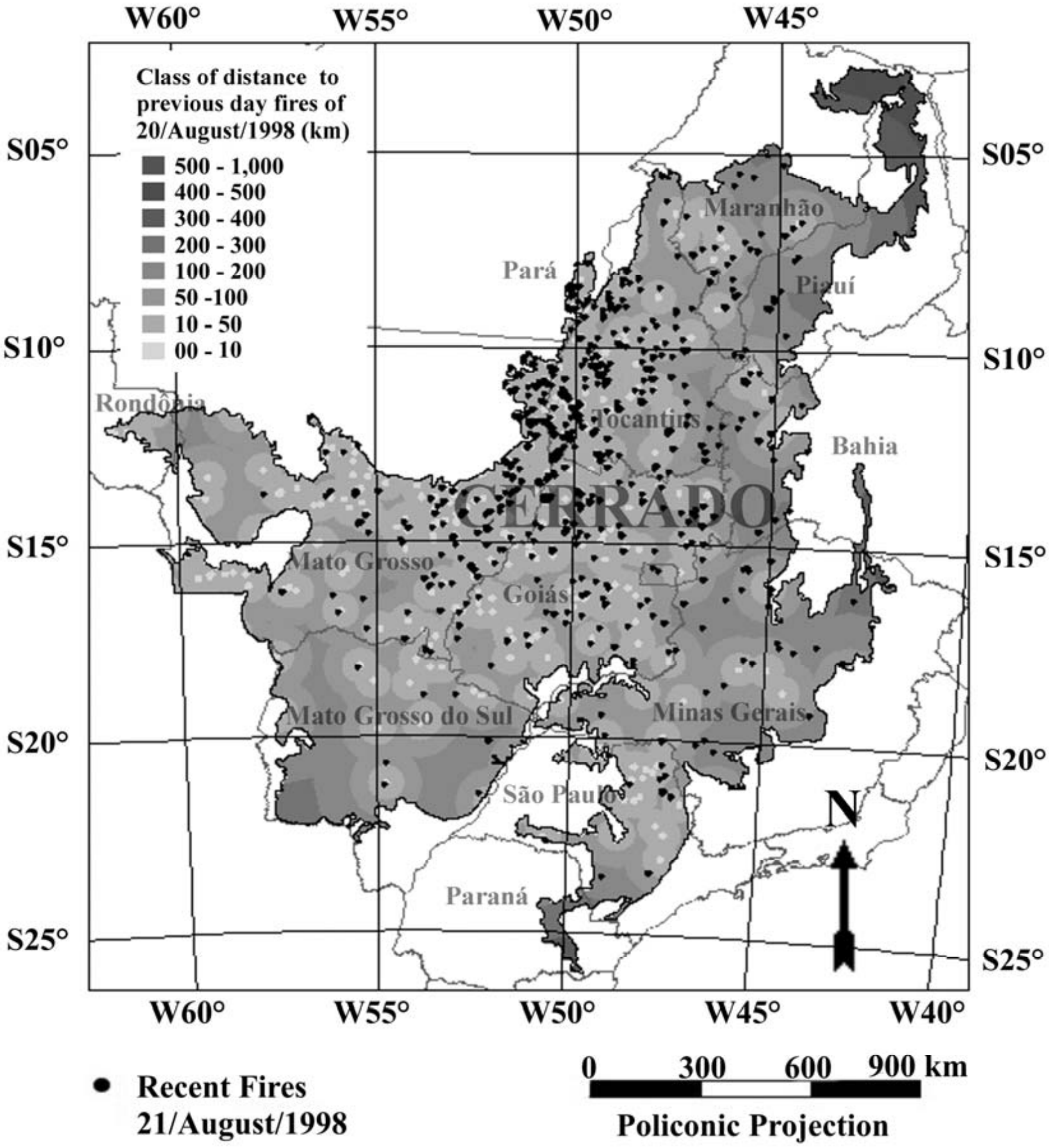


Fig. 6 – Map of distance to previous day fire (20 August 1998) with recent fires (21 August 1998) in the Cerrado.

12

Table 2 – Area of the Cerrado occupied by the classes of distance to road network.

Class of distance to road network (km)	Class of distance to road network - Area			
	Area (km^2)	Percentage (%)	Cumulative area (km^2)	Cumulative percentage (%)
0 - 5	337,194	15.7	337,194	15.7
5 - 10	244,975	11.4	582,169	27.1
10 - 15	230,175	10.7	812,344	37.8
15 - 20	192,375	9.0	1,004,719	46.8
20 - 25	176,344	8.2	1,181,063	55.0
25 - 30	139,750	6.5	1,320,813	61.5
30 - 35	123,219	5.7	1,444,031	67.2
35 - 40	107,313	5.0	1,551,344	72.2
40 - 45	92,225	4.3	1,643,569	76.5
45 - 50	75,244	3.5	1,718,813	80.0
50 - 60	121,788	5.7	1,840,600	85.7
60 - 70	90,638	4.2	1,931,238	89.9
70 - 80	66,494	3.1	1,997,731	93.0
80 - 90	46,756	2.2	2,044,488	95.2
90 - 100	29,656	1.4	2,074,144	96.6
100 - 150	65,263	3.0	2,139,406	99.6
150 - 200	7,719	0.4	2,147,125	100.0

4.2. Overlapping of the recent fires data with the distance maps

The overlap of the recent fire data with the distance maps —Fig. 5 for the road network and Fig. 6 for the previous day fires— allowed the estimation of the incidence of recent fires according to distance classes. When considering the distance classes for the two indicators of anthropic activity —road network and previous day fires—, it was observed that a larger number of recent fires occurred in areas close to the two indicators.

Table 3 – Average area of the Cerrado occupied by classes of distance to the previous day fires.

Class of distance to previous day fires (km)	Class of distance to previous day fires - Area			
	Area (km^2)	Percentage (%)	Cumulative area (km^2)	Cumulative percentage (%)
0 - 5	10,273	0.5	10,273	0.5
5 - 10	23,160	1.1	33,433	1.6
10 - 15	36,213	1.7	69,646	3.3
15 - 20	41,982	2.0	111,628	5.3
20 - 25	49,153	2.3	160,780	7.6
25 - 30	50,682	2.4	211,462	10.0
30 - 35	52,418	2.4	263,880	12.4
35 - 40	53,927	2.5	317,807	14.9
40 - 45	54,189	2.5	371,996	17.4
45 - 50	51,853	2.4	423,849	19.8
50 - 60	98,554	4.6	522,404	24.4
60 - 70	92,613	4.3	615,017	28.7
70 - 80	86,542	4.0	701,559	32.7
80 - 90	80,239	3.7	781,797	36.4
90 - 100	74,935	3.5	856,733	39.9
100 - 150	309,266	14.4	1,165,998	54.3
150 - 200	220,251	10.3	1,386,249	64.6
200 - 250	162,335	7.6	1,548,584	72.2
250 - 300	122,862	5.7	1,671,446	77.9
300 - 350	93,112	4.3	1,764,558	82.2
350 - 400	72,668	3.4	1,837,225	85.6
450 - 450	58,768	2.7	1,895,993	88.3
450 - 500	49,641	2.3	1,945,634	90.6
500 - 1,000	180,824	8.4	2,126,458	99.0
1,000 - 3,000	20,623	1.0	2,147,081	100.0

When considering the road network, 14% of the recent fires occurred in the distance class of 0-5 km and 10% occurred in the distance class of 5-10 km with a decreasing trend (Table 4). With respect to the previous day fires, 12% of the recent fires occurred in the distance class of 0-5 km and 12% occurred in the distance class of 5-10 km also with a decreasing trend (Table 5). Therefore, 24% of the recent fires occurred at up to 10 km from both anthropic indicators. From this distance onwards, given the same distance, larger number of recent fires occurred closer to the road network than to the

14

previous day fires. In the same way, given the same number of recent fires, incidence was higher with respect to the road network than with the previous day fires. Therefore, the incidence of recent fires was higher at places near the anthropic activity indicators with a tendency to decrease according to the distance increase, suggesting that vegetation areas close to the road network and to the previous day fires are more susceptible to fire. These results are in agreement with Vasconcelos et al. (1991) that showed vegetation fire susceptibility decreasing with the increase of the distance to anthropic activities.

Table 4 – Recent fires incidence in relation to the distance to the road network in the period from May to October 1998.

Class of distance to road network (km)	Recent fires incidence - Number			
	Number	Percentage (%)	Cumulative number	Cumulative percentage (%)
0 - 5	1,558	14	1,558	14
5 - 10	1,162	10	2,720	24
10 - 15	1,163	11	3,883	35
15 - 20	1,029	9	4,912	44
20 - 25	1,030	9	5,942	53
25 - 30	879	8	6,821	61
30 - 35	781	7	7,602	68
35 - 40	530	5	8,132	73
40 - 45	491	4	8,623	77
45 - 50	386	3	9,009	80
50 - 60	693	6	9,702	86
60 - 70	600	5	10,302	91
70 - 80	393	4	10,695	95
80 - 90	230	2	10,925	97
90 - 100	67	1	10,992	98
100 - 150	236	2	11,228	100
150 - 200	7	0	11,236	100

15

Table 5 – Recent fires incidence in relation to the distance to the previous day fires in the period from May to October 1998.

Class of distance to previous days fires (km)	Recent fires incidence - Number			
	Number	Percentage (%)	Cumulative number	Cumulative percentage (%)
0 - 5	1,376	12	1,376	12
5 -10	1,308	12	2,684	24
10 -15	882	8	3,566	32
15 -20	691	6	4,257	38
20 -25	680	6	4,937	44
25 -30	514	5	5,451	49
30 -35	632	5	6,083	54
35 -40	544	5	6,627	59
40 -45	402	4	7,029	63
45 -50	329	3	7,358	66
50 -60	718	6	8,076	72
60 -70	458	4	8,534	76
70 -80	350	3	8,884	79
80 -90	291	3	9,175	82
90 -100	229	2	9,404	84
100 -150	722	6	10,126	90
150 -200	358	3	10,484	93
200 -250	265	3	10,749	96
250 -300	166	1	10,915	97
300 -350	127	1	11,042	98
350 -400	65	1	11,107	99
450 -450	47	0	11,154	99
450 -500	29	0	11,183	99
500 –1,000	53	1	11,236	100
1,000 – 3,000	0	0	11,236	100

4.3. Recent fires incidence and area of the distance classes

The cumulative percentage of areas in the distance classes in relation to the road network (Table 2) is numerically similar to the cumulative percentage of recent fires incidence in the same classes (Table 4). This is emphasized in Fig. 7 by the coincidence of the curves related to the road network. Considering the previous day fires, however, the cumulative percentage of areas in the distance classes (Table 3) did not follow the increase of the cumulative percentage of the recent fires in the incidence in the classes

(Table 5). This is observed in Fig. 7 by the difference on the previous day fire curves that are only coincident towards the end.

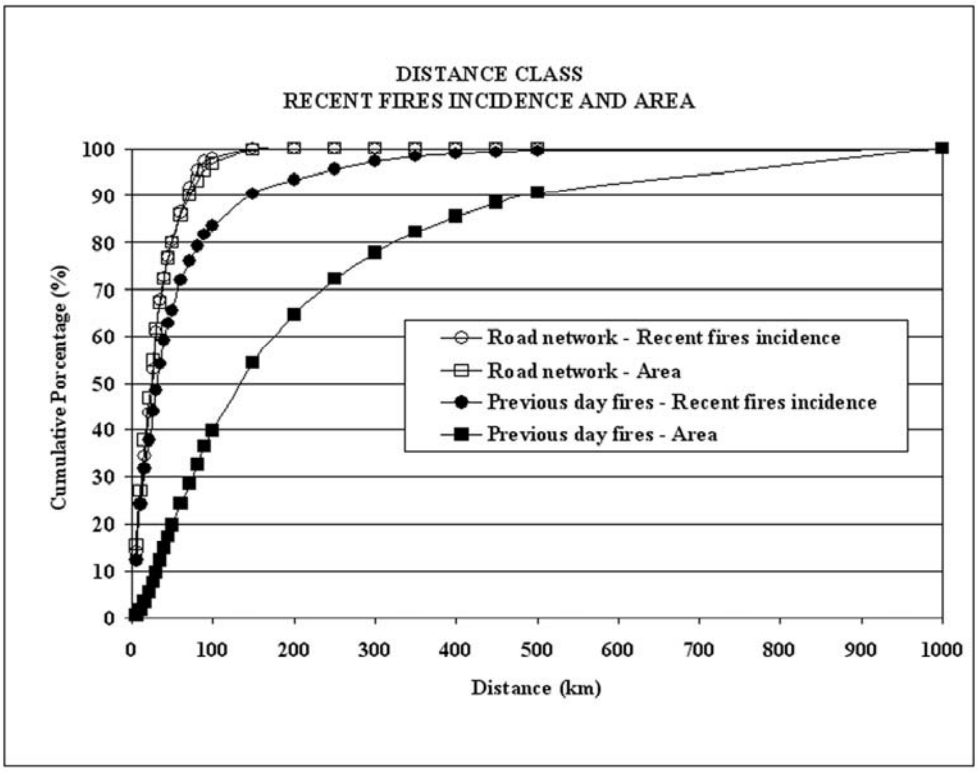


Fig. 7 – Cumulative percentage of the recent fires and area related to the distance to the road network and to the previous day fire classes from May to October 1998.

As previously considered, when taking a single distance in relation to both anthropic activity indicators, the cumulative percentage of recent fires was higher for the road network than for the previous day fires, except at the distance of up to 10 km, where the percentages are similar (Tables 4 and 5). On the other hand, the cumulative area of the distance classes in relation to the road network was much higher than the area of the same classes in relation to the previous day fires (Tables 2 and 3). The data showed that, although the incidence of recent fires at a distance classes of up to 5 km and to 10 km from both indicators was similar (12% and 24% respectively), the area occupied by these distance classes was much smaller when considering the previous day fires (0.5% and 1.6% respectively), with respect to the road network (17.7% and 27.1% respectively).

For the road network, 24% of the recent fires occurred at up to 10 km, corresponding to distance class area of around 582,000 km^2 or around 27% of the total Cerrado area. In addition, up to 10 km from the previous day fires occurred at the same 24% of the recent fires, but corresponding to distance class area of around 33,000 km^2 or around 2% of the total Cerrado area. Therefore, when planning the prevention of fire, it is advantageous to use data from the distance to the previous day fires, which would allow fire prevention and fight with less personnel and equipment. That is supported by the fact that the variable distance to the previous day fires delimitated smaller areas and same fire incidence than variable distance to the road network.

5. Conclusions

The main findings on this work are:

- The probability of fire occurrence at a particular location is inversely proportional to the distance from the two anthropic activity indicators analysed here: road network and previous day fires. The fire incidence was higher at areas close to those indicators and, therefore, these areas are more susceptible to the occurrence of new fires. About a quarter of the recent fires occurred up to 10 km from the anthropic activity indicators. Therefore, the vegetation close to these indicators is more susceptible to fire.
- Considering that about a quarter of the fire spots occurred at about the same distance in relation to both anthropic activity indicators and that more than a half of the fire spots occurred at up to 25 km from the road network and 35 km from the previous day fires, these two indicators must be used in the fire susceptibility indexes for the Cerrado area,

having a direct application in the prevention of future fires in the Cerrado.

- When fire prevention is the goal, we consider that the use of the distance from the previous day fires is advantageous. This variable covered a small classes area and is closely located the fires that will probably occur, allowing the use of less personnel and equipment for fire prevention and fight.

Further studies suggested include: (i) the utilization of other anthropic activity indicators such as the proximity of urban centres, annual crops areas, natural and cultivated pastures and the history of previously burned areas; (ii) methodologies considering remotely sensed data acquired at other time interval rather than the data used here; (iii) the use of a more detailed road network map with marginal and vicinal roads; (iv) the use of combined anthropic activity indicators.

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19

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