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Lightning Fires in a Brazilian Savanna National Park: Rethinking Management Strategies

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ABSTRACT / Fire occurrences and their sources were monitored in Emas National Park, Brazil (17°49′–18°28′S; 52°39′–53°10′W) from June 1995 to May 1999. The extent of burned area and weather conditions were registered. Forty-five fires were recorded and mapped on a GIS during this study. Four fires occurred in the dry winter season (June–August; 7,942 ha burned), all caused by humans; 10 fires occurred in the seasonally transitional months (May and September) (33,386 ha burned); 31 fires occurred in the wet season, of which 30 were caused by lightning inside the park (29,326 ha burned), and one started outside the park (866 ha burned). Wet season lightning fires started in the open vegetation (wet field or grassy savanna) at a flat plateau, an area that showed significantly higher fire incidence. On average, winter fires burned larger areas and spread more quickly, compared to lightning fires, and fire suppression was necessary to extinguish them. Most lightning fires were patchy and extinguished primarily by rain. Lightning fires in the wet season, previously considered unimportant episodes, were shown to be very frequent and probably represent the natural fire pattern in the region. Lightning fires should be regarded as ecologically beneficial, as they create natural barriers to the spread of winter fires. The present fire management in the park is based on the burning of preventive firebreaks in the dry season and exclusion of any other fire. This policy does not take advantage of the beneficial effects of the natural fire regime and may in fact reduce biodiversity. The results presented here stress the need for reevaluating present policies and management procedures concerning fire in cerrado conservation areas.

There is a consensus that fire has been occurring in tropical savannas for thousands of years, shaping the landscape and selecting for adapted flora and fauna. It has also been accepted that ancient fires were caused by natural events, mostly lightning, but also by volcanic activity and friction between rocks. Nevertheless, after humans came to gather in social groups, they became the main cause of wildfires, greatly increasing the fire frequency and changing fire regimes, from cool wet-season fires to more intense dry-season fires (Komarek 1972, Edwards 1984, Coutinho 1990, Goldammer 1993, Pyne 1993, Whelan 1995).

However, the belief that almost all tropical fires at present are anthropogenic has not been adequately demonstrated. Lightning fire outbreaks are poorly documented in tropical ecosystems, although there are some records (Tutin and others 1996, Middleton and others 1997). In Brazil, it was probably this lack of recorded fire strikes that led to the opinion that lightning fires are rare in cerrados, the Brazilian savannas. As Soares (1994) states "in cerrados . . . lightning might even be an important cause for fires; however, studies to confirm or to reject this hypothesis do not exist."

KEY WORDS: Wildfire; Lightning; Brazilian savanna; Cerrado; Fire management; Emas National Park

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The cerrado biome is the second largest realm in Brazil, occupying over 1.8 million km^2 on the Brazilian Central Plateau, at altitudes from 300 to 1,000 m above sea level (Ab'Saber 1971). Although patches of forest and grassland forms appear in the cerrado landscape, it is dominated by savanna forms, in a gradient from open grassy to woodland savannas. The more open the savanna structure, the more fire prone it is. On the other hand, forest patches are not fire prone and only burn when fire is intense.

The tropical humid climate in the cerrado region, with a dry winter (3–6 months) and a wet summer, imposes a strong seasonality to the vegetation, especially grasses, which dry out in the winter. At this time of the year, cattle grazers used to burn cerrados to promote grass regrowth and to supply palatable forage to cattle. Subsistence farmers also used to burn arable areas to prepare the land for cultivation in the wet season. Therefore, cerrados managed in these ways (almost all, except the natural reserves) sustain little fuel to be burned by natural lightning fires in the next wet season.

Hence, especially because of the management that humans apply to cerrados, the burning season runs from May to September, when the herbaceous vegetation is dry and more flammable, and fire spreads easily from farmlands to natural areas. Early fires in May–June are usually cool fires and burn the area patchily as the vegetation still has high water content. As the dry season continues the curing status of the grass layer increases and fire intensity also tends to increase. Fire outbreaks peak by the end of the dry season (July–August) (Coutinho 1990, Pivello 1992, Mistry 1998). In the early wet season (September–October), fire occurrences decrease, although the vegetation is still able to carry a fire (H. S. Miranda, personal communication).

Present-day discussion on the causes of wildland fires, a subject explored since the 1970s (Komarek 1972, Edwards 1984), is not only a matter of conjecture; it may be important to management approaches and policies for conservation areas. Yet, little concern given to the natural fire dynamics in Brazil, and the misconceptions about fire effects in natural environments led the governmental sectors responsible for nature conservation to reject any fire in cerrado conservation areas, either natural or prescribed. The environmental legislation, although very conservative, has permitted the use of fire since 1989 for managing nature reserves (Federal Decree No. 97635 from 10 April 1989) but, in fact, decision-makers in the governmental body rarely allow fire management in parks and reserves, even though it can be a very useful and cheap management tool.

Several environmental benefits may be brought by fire in savannas, especially the stimulus to nutrient recycling and to sprouting, fruiting, and seeding of several plant species; it also increases the vigor and palatability of a number of herbaceous species. Different fire regimes (fire type, frequency, intensity, and season) may favor distinct groups of species or may consume more or less intensively the accumulated fuel (Warming 1908, Coutinho 1980, 1982, 1990, Kruger 1984, Christensen 1985, Pivello 1992, Pivello and Coutinho 1992, 1996, Whelan 1995, Pivello and Norton 1996). Such fire outcomes may result in management ends, as wildfire control, food supply to native fauna, weed control, and the maintenance of biodiversity and ecological processes (Pivello 1992, Pivello and Coutinho 1996, Pivello and Norton 1996).

As fire consumes the fuel, burned patches may act as firebreaks to unburned areas and management burnings can be used to avoid the spread of wildfires. Still, a savanna landscape formed by a mosaic of unburned patches and patches burned at different time intervals is able to maintain a great variety of both sun-loving fire-prone species and those from woodland savanna. To achieve these goals, prescribed fires are used in parks of diverse ecosystems worldwide as a management tool, for example, in the North American Yellowstone and Everglades national parks and in the Australian Kakadu and Uluru national parks, among many others (Saxon 1984, Parsons and others 1986, Schullery 1989, Australian National Parks and Wildlife Service 1991, Conroy and others 1997, Russel-Smith 1997).

In Brazilian protected areas, where an antifire policy prevails, the consequence has been the occurrence of periodic and severe wildfires, when fuels accumulate and fire becomes inevitable, threatening animals and humans. In Emas National Park and Chapada dos Veadeiros National Park, for example, severe fires occur every 3–4 years (Redford 1985, Pivello 1992, 1996, Pivello and Coutinho 1992, França and Setzer 1997). Severe wildfires in Emas National Park occurred in 1975, 1978, 1985, 1988, 1991, and 1994 and burned 74–93% of the 132,133 ha of the park, killing a number of vertebrates (I.B.D.F. 1981, Redford 1985, Silveira and others 1996, França and Setzer 1997). Furthermore, the critical problem of invasions of alien grasses in cerrados (Pivello et al. 1999a, 1999b) could, in some cases, be controlled by low-intensity prescribed fires (Pivello 1992, Pivello and Norton 1996).

The objective of this study is to demonstrate the importance of lightning fires in the cerrados and to emphasize the need to consider the beneficial effects of these fires in management strategies. It is also important to stress that we are justifying the use of prescribed fires to manage savannas, and not tropical forests, as the functioning and dynamics of these ecosystems are totally different; as a rule, fire seriously damages tropical forests (see Nepstad and others 1999).

The Study Area

Emas National Park is located in the core region of the cerrado biome, the Brazilian savanna, in the SW of Goiás State, Central Brazil (17°49′–18°28′S and 52°39′–53°10′W) (Figure 1). It is the largest (132,133 ha) and most important protected cerrado area, because of its diverse flora and fauna (I.B.D.F. 1981, Redford 1987). In this park, cerrado fauna is abundant and easily observed. Several threatened species, including the giant armadillo (*Priodontes maximus*), giant anteater (*Myrmecophaga tridactyla*), pampa cat (*Felis colocolo*) and puma (*Felis concolor*), still occur there (Redford 1983, Machado and others 1998).

Regional climate is tropical and humid, with wet summers and dry winters (June–August), typical of savannas (zonobiome II, according to Walter and Lieth) (Walter 1971). Annual rainfall ranges from 1,200 to 2,000 mm (França and Setzer 1997, and this study), concentrated from October to March (Figure 2a). Ac-

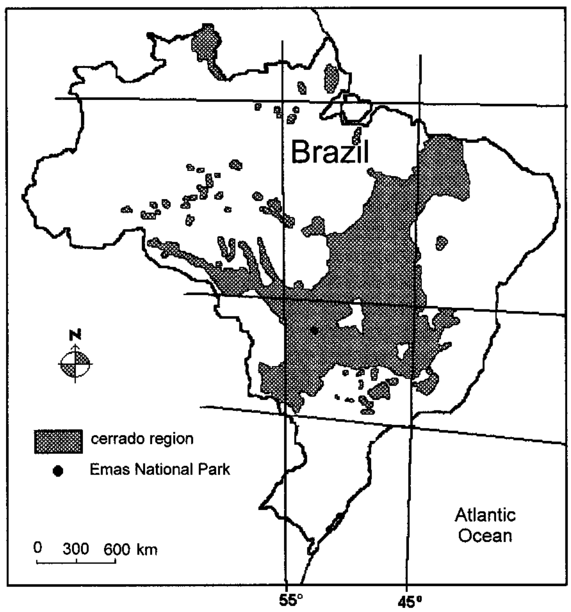


Figure 1. Cerrado region (according to I.B.G.E. 1992) and the location of Emas National Park, Brazil.

cording to the rainfall and soil water regime, May and September are considered transitional months, since they represent, respectively, the end and the onset of the rainy season (Figure 2). Frost is expected every winter, in June and/or the beginning of July.

Three quarters of Emas National Park consist of flat tableland, 820–888 m in elevation; the remaining area consists of hilly terrain, 720–820 m in elevation. A gradient of open savanna types (68.1%) and dense savanna (cerrado *sensu stricto*) (25.1%) can be found in the park, as well as wet fields (4.9%) and riparian and mesophyllous forests (1.2%) (Figure 3).

Up to 1984, the park was exploited by farmers for cattle ranching and fire was used to promote forage regrowth. After that time, the park was totally fenced, and cattle were no longer permitted inside it. Since then, a policy of fire exclusion was established in the park, except for the annual burning of 314 km of preventive firebreaks (I.B.D.F. 1981, IBAMA 1993). In spite of this, uncontrollable wildfires occur every 3–4 years (França and Setzer 1997).

The federal government owns all the parkland, and there are no residents inside it. Visitors to the park are always accompanied by an authorized guide.

Methods

Fire occurrences in Emas National Park were recorded in the field from June 1995 to May 1999 through direct observation. Additionally, the park was checked for evidence of spot fires, by airplane, on three occasions during the study period. We recorded for each fire, the time it started and stopped and local weather conditions during the burn. After each fire, the burned area was immediately visited in order to locate its perimeter, with the aid of a GPS (global positioning system). The location of the initial fire point was estimated by analyzing the remaining grass stalks, ash patterns, and wind behavior, as suggested by Cheney and Sullivan (1997).

Local rainfall was registered during the study period by 35 rain gauges installed in the park, and additional climatic data were obtained from the nearest climatic station, in Mosteiro São José, Mineiros Municipality, GO (França and Setzer 1997). The climatic data were used to build a climatic diagram according to Walter and Lieth (Walter 1971) (Figure 2a) and a water balance diagram, according to Thornthwaite and Mather (1955) (Figure 2b).

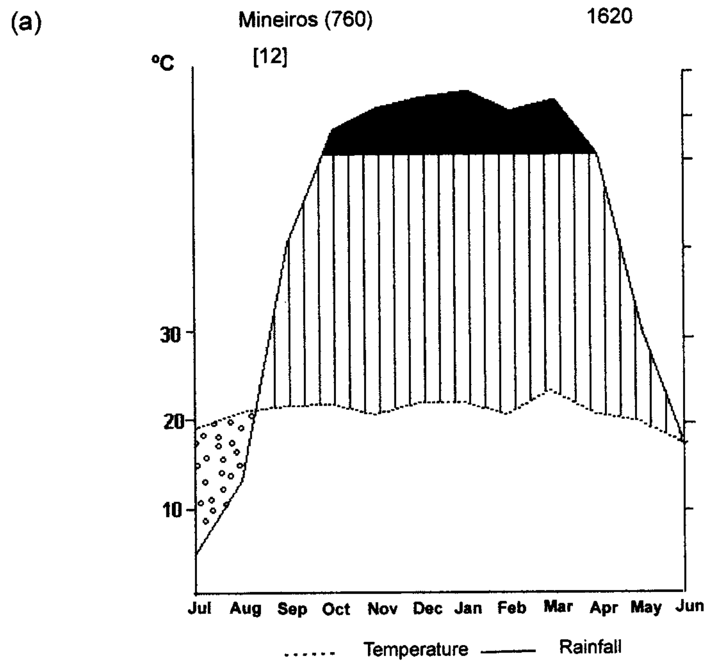
Using GIS software (IDRISI for Windows, version 2.0, Clark University), each fire occurrence was mapped and the perimeter and extent of each burned area was calculated.

A grid of 4 × 4 km was overlaid on the park map and the randomness of the distribution of fire starts in each cell was statistically tested by a chi-square test (Kershaw and Looney 1964).

Fires were classified as natural or human-induced. When the lightning strike that caused a fire had not been observed in the field, the fire would be considered natural if thunderstorms occurred at the time of fire event, the fire focus was distant from park limits, and visitors had not been in the park the day of the fire event. If one or more of these conditions were not satisfied, the fire would be considered human-induced. We considered each natural fire as resulting from one lightning strike.

Results

Fire outbreaks during the study period are presented in Table 1. Forty-five fires were registered and five of them were considered human-induced. Forty-one fires were identified immediately after they started and four small burned areas were detected by airplane. Three of the anthropogenic fires were caused by the park staff when burning firebreaks, and the other two came from farms outside the park, as observed in the field. Four human-induced fires occurred during the dry season, when vegetation was undergoing a water deficit (Figure 2b), and burned a total of 7,942 ha; the other one occurred in January and burned 866 ha. Ten



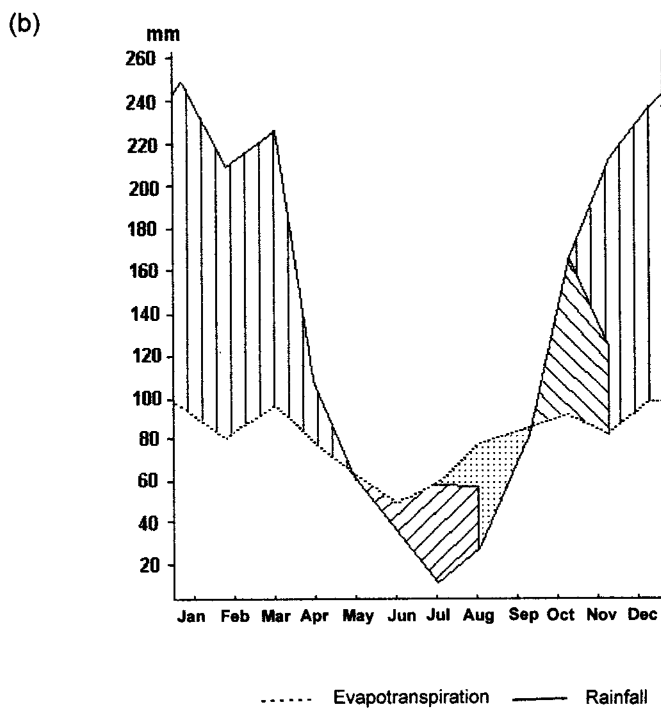


Figure 2. Climatic diagram (a), following Walter and Lieth (Walter 1971), and the regional water balance (b), according to Thornthwaite and Mather (1955), for Emas National Park region. Data from the nearest climatic station, in Mosteiro São José, Mineiros municipality, Goiás state (França and Setzer 1997) and from this study, for the period of 1985 to 1997. In a: black = excess water, vertical strips = regular water supply, dotted = water deficit. In b: vertical strips = surplus soil water, right dashed = soil water withdrawal, left dashed = soil water replenishment, dotted = water deficit).

fires happened in the seasonally transitional months (May and September), burning 33,386 ha; 31 fires occurred in the wet months, 30 of which were caused by lightning (29,326 ha burned) and one of which came from outside the park (866 ha burned). Multiple fire points caused by a single lightning strike were not observed, as in this case the fire points would appear near each other and all fires registered were isolated. Small spot fires merging to a large fire were not observed.

The majority of wet-season lightning fires (76%) were patchy, burned small areas (less than 500 ha)

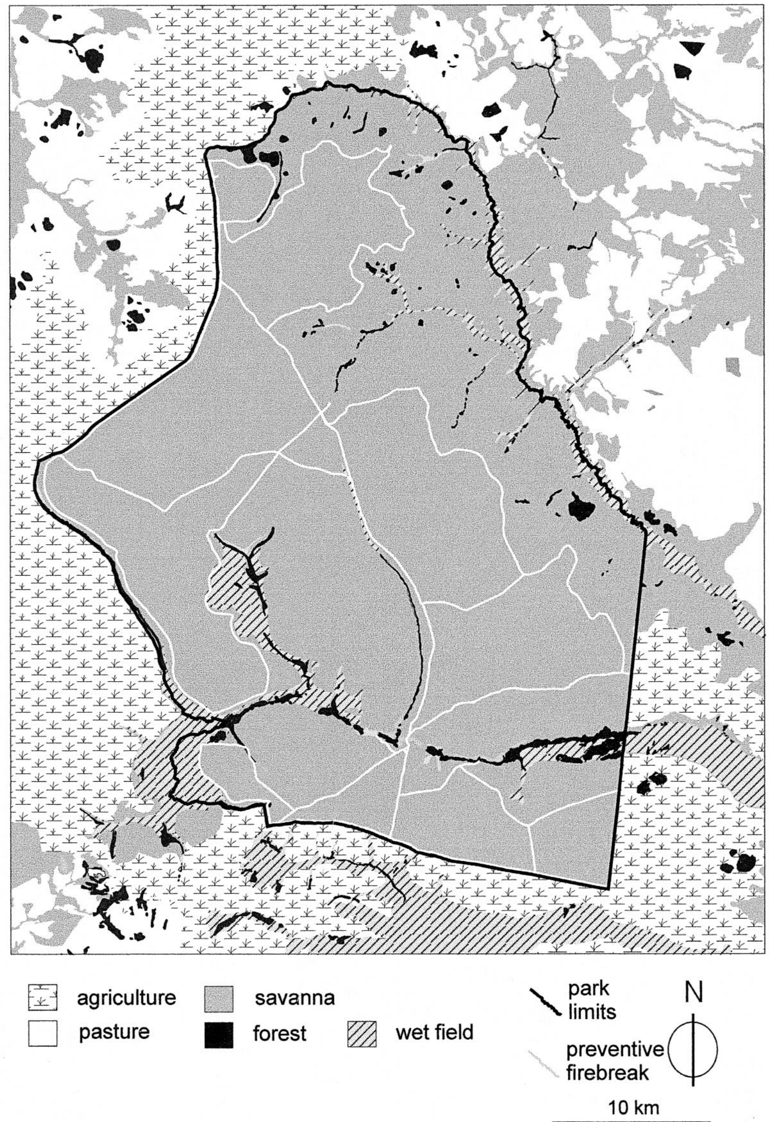


Figure 3. Vegetation forms in Emas National Park, Brazil.

(Figure 4) and were extinguished primarily by rain (Table 2); active fire suppression was applied in only two of them, and even so the main causes for their extinction were rain, a natural barrier such as river or gallery forest, or a burned firebreak. In contrast, dry-season (June–August) fires burned larger areas compared to wet season lightning fires, spread more quickly, and required vigorous suppression efforts to bring them under control (Tables 1 and 2). February was the month with the highest fire incidence (11 fire outbreaks with 1,312 ha burned), followed by September (eight outbreaks with 24,020 ha burned) (Figure 5).

During the study period, 53.4% of the park area did not burn; 38.1% burned once; 8.4% burned twice, and only 0.1% of the park burned three times (Figure 6). Examination of the spatial distribution of fires revealed some places in the park where fire outbreaks were more frequent, and this was confirmed statistically when analyzed against cells in a grid ($\chi^2 = 37.7$; $df = 2$; $P < 0.001$). All lightning fires started on the flat plateau, which occupies the highest elevation in the park and is covered mostly by open vegetation (wet field or grassy savanna) (Figures 3 and 6).

Discussion

Although scientists have long recognized lightning as an important cause of wildland fires (Warming 1908, Komarek 1972, Coutinho 1980, 1990, Tutin and others

Table 1. Fire outbreaks registered from June 1995 to May 1999 in Emas National Park, Brazil

	Natural fire		Human-induced fire		
Date	Number	Area (ha)	Number	Area (ha)	Total area (ha)
Jun 95	—	—	2	6,780	6,780
Aug 96	—	—	1	792	792
Sep 96	4	4,628	—	—	4,628
Oct 96	1	9,619	—	—	9,619
Dec 96	2	6,767	—	—	6,767
Feb 97	4	275	—	—	275
Mar 97	2	23	—	—	23
May 97	1	61	—	—	61
Jun 97	—	—	1	370	370
Sep 97	4	19,390	—	—	19,390
Oct 97	1	1	—	—	1
Nov 97	1	70	—	—	60
Jan 98	2	323	—	—	323
Feb 98	2	377	—	—	377
Mar 98	1	378	—	—	378
Nov 98	1	1,592	—	—	1,592
Dec 98	3	2,716	—	—	2,716
Jan 99	4	4,164	1	866	5,030
Feb 99	5	659	—	—	659
Mar 99	1	2,362	—	—	2,362
May 99	1	9,307	—	—	9,307
Total	40	62,702	5	8,808	71,510

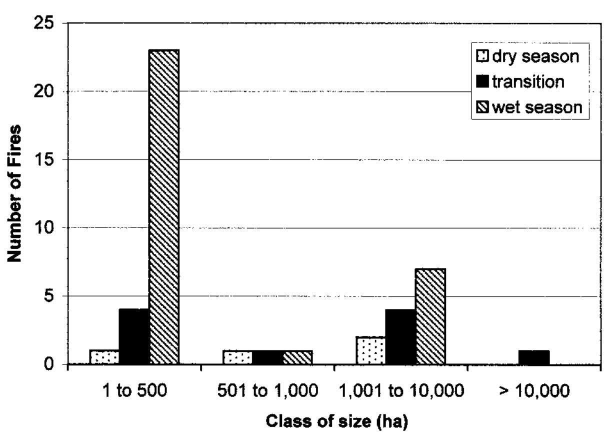


Figure 4. Fire outbreaks according to size classes (hectares) and fire season, in Emas National Park, Brazil.

1996, Middleton and others 1997), records of fire outbreaks that included precise information on location, area burned, and ignition source were not previously available for the cerrados. In most cerrado parks and reserves, human-caused fires are, indeed, much more frequent than natural fires and originate at nearby farms or urban areas (Pivello and Coutinho 1992).

The low incidence of anthropogenic fires in the study area may be explained by several reasons. First, preventive firebreaks, especially the ones located at the park limits, had been maintained in reasonably good condition by annual burning during the dry season, thus avoiding the spread of fires coming from outside the park. Second, mechanical agriculture now prevails around the park, where fire is not frequently used. Third, the fire-combat staff, although numbering only a few persons and limited equipment, was present in the park during the entire dry season and ensured a rapid response when fires began. Finally, visitors in the park were always guided by an authorized person and an educational program was developed for farmers who live near the park. However, these measures were not able to suppress fire from the park because when human-induced fires are repressed natural lightning fires predominate. That was evidenced by the highest fire incidence during the wet months, probably related to the number of lightning strikes in that period, since heavy showers with thunderstorms and lightning are frequent in the wet season.

Very few lightning strikes have been documented in the cerrado region; the best available records come from Pinto and others (1996), who registered 0.4 occurrences/km^2 in a place (Uberlândia, MG, Brazil) that lies at the same latitude as the Emas Park, about 400 km east. Considering that in the present study each natural fire was started by only one lightning strike and taking the lightning records of Pinto and others (1996), we

Table 2. Main causes of fire extinction according to fire season in Emas National Park, Brazil

Causes of fire extinction	Dry season	Transition	Wet season	Area (ha)
Natural causes (rain, natural barriers or low temperature)	0	4	14	5.459
Natural causes + preventive firebreak	0	2	15	12.367
Natural causes + suppression	0	2	0	8.383
Natural causes + preventive firebreak + suppression	0	1	1	25.686
Preventive firebreak	0	1	0	10.807
Suppression	0	0	0	0
Preventive firebreak + suppression	4	0	1	8.808
Total	4	10	31	71.510

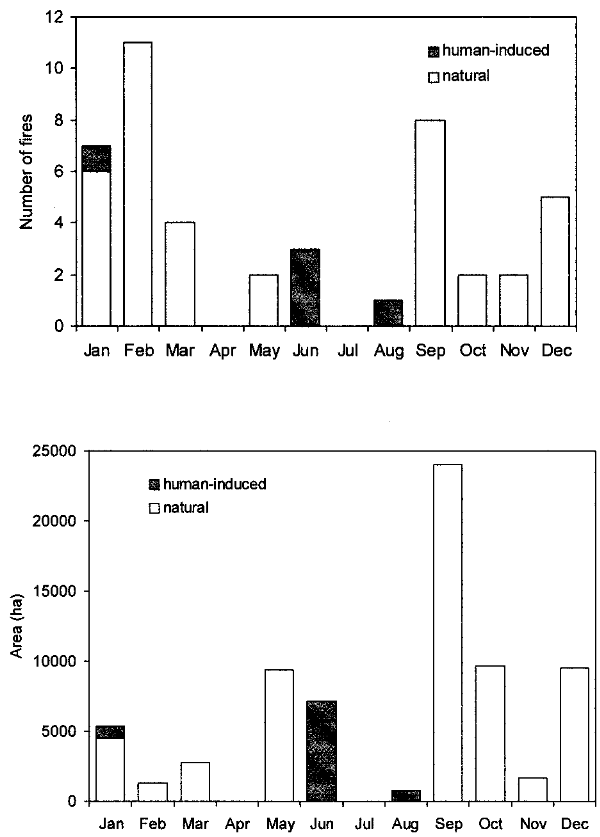


Figure 5. Total fire outbreaks (a) and the total area (hectares) burned per month (b), in Emas National Park, Brazil, from June 1995 to May 1999.

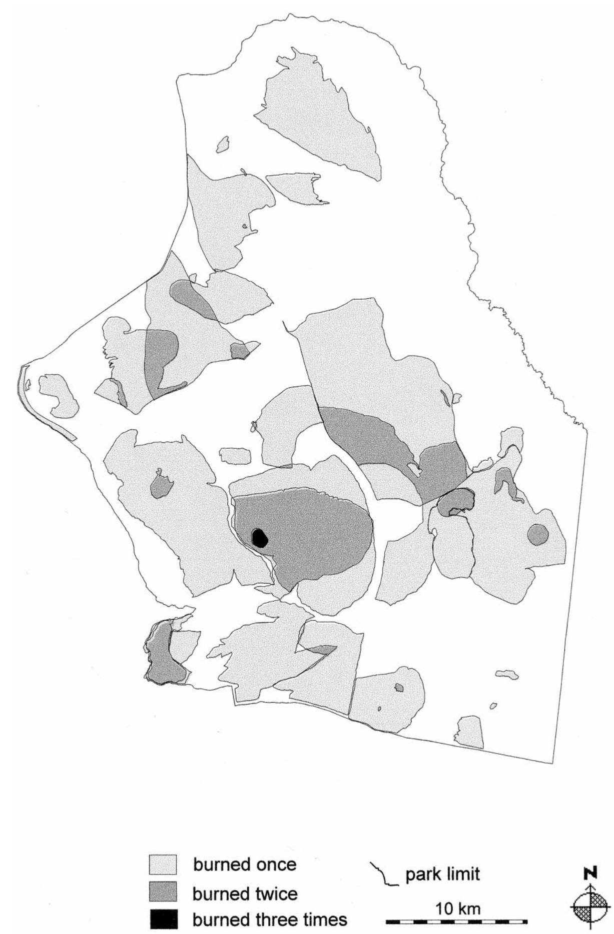


Figure 6. Fire frequency in Emas National Park, Brazil, from June 1995 to April 1999.

estimate that 1%–2% of the lightning strikes cause wildfires in Emas National Park, not a negligible figure.

Although the highest fire incidence happened in February (wet season), the total area burned (1,312 ha) was relatively small, in contrast to September (transitional month), when the largest cumulative area burned (24,020 ha). Large fires in September were probably related to weather and fuel conditions. By this time of the year, the vegetation is cured and undergoing severe water deficit (Figure 2b), the fuel is dry and plentiful, especially if frosts occur (Pivello 1992, Pivello and Norton 1996) and where the grass *Tristachya leiostachya* is dominant (Ramos-Neto and Machado 1996). The onset of the wet season in September brings heavy showers with thunderstorms and lightning, causing fire outbreaks and spread (Schule 1990, Pivello 1992, Pivello and Norton 1996).

Another factor that seems to influence fire occurrence is the elevation. Higher lightning fire occurrence was registered in elevated plateaus. Frequent lightning fires at high elevations have also been reported in Costa Rica dry forests (Middleton and others 1997). The altitude probably influences local meteorological conditions and cloud formation, resulting in greater lightning incidence. This phenomenon, however, deserves more investigation.

The present study shows the importance of natural fires, at least in the most important protected cerrado, Emas National Park. Cool fires in the wet season and more intense fires in the transitional months may dominate the natural pattern in the region studied, instead of high-intensity winter fires, as has been believed up to the present time. Wet-season fires usually burn small areas due to the high moisture content in the vegetation (Pivello 1992) and are rapidly extinguished by the heavy summer rains. Wet-season fires contribute to the creation of a mosaic of low-fuel patches, which may function as natural firebreaks and reduce the spread of subsequent fires. This patchy landscape also provides shelter for animals during a fire and maintains seed banks of less fire-tolerant plant species; patchy burns may increase the area of ecotones, permitting higher diversity. In contrast, winter fires are hot, spread much quicker, and may burn huge areas if fuel is abundant, as often occurs under full fire-suppression policies.

As virtually no records of wet-season fires in cerrados exist, studies and experimentation considering fire effects in flora and fauna until now have only considered dry-season fires. In the case of Emas National Park, that condition would be unrealistic, as most fires occur between September and May. In that case, the response of plants and animals to fire may be different than those described in the literature. For instance, studies on plant biomass production after fire indicate very different results according to whether the burn occurs in June, September, or November (Ramos-Neto, personal communication).

Conclusion: Are Present Fire Management Strategies Adequate?

The lack of more precise information on cerrado fires and the fact that policy-makers are not well informed on recent advances in fire ecology have led to inadequate management policies concerning fire in cerrado preserves (Pivello 1992). Full-suppression policies come from conservative attitudes and are based on past ideas about the harmful effects of wildland fires. This is reflected in the fact that legislation permitting the use of management burning, in special cases, was not passed until 1988/89 (IBDF Law No. 231-P/88; CONAMA Resolution No. 011 from 14 December 1988; Federal Decree No. 97635 from 10 April 1989).

The policy of total fire suppression has proved to be inadequate in cerrado preserves, as extensive and hot fires periodically occur when fuels accumulate, demanding huge efforts and cost to be controlled. A proper management policy in protected cerrados should be based on continuous monitoring and assessment of flora and fauna responses to specific fire regimes. It should include the possibility of using natural or periodic hazard-reduction fires in view of all the benefits fire can bring to the ecosystem.

In the case of Emas National Park, we suggest that natural lightning fires should be allowed to burn and should be monitored; fire suppression should occur only if the fire becomes too large or intense. Fuels should also be monitored and a patch-burning strategy using prescribed fires could be adopted for hazard reduction. The effectiveness of this strategy has been demonstrated in savanna parks elsewhere in the world (Edwards 1984, Bradstock and Bedward 1997, Gill 1997).

Preventive firebreaks must be maintained, especially at the park limits, because they are reasonably effective in containing the spread of winter fires. However, the number of firebreaks and their location and width should be reviewed, especially if a patch-burning strategy is adopted. At present, firebreaks are kept clean of fuel by burning strips 25–60 m wide, by the middle of the dry season. We recommend they be burned early in May, both to follow a more natural burning pattern (since lightning fires still occur in May) and because burning is safer when vegetation is not so dry. Guidelines for prescribed fires in cerrados are discussed in more detail by Pivello (1992) and Pivello and Norton (1996).

In conclusion, a fire management policy that integrates natural and prescribed fires with conservation goals should be adopted in cerrado preserves. The present policy concerning wildland fire in Emas National Park may not protect its biodiversity on the long term because of the damage to native flora and fauna resulting from uncontrollable winter fires. A flexible strategy of allowing and monitoring wet-season fires and patch-burning when necessary would be a more appropriate approach to maintaining the park natural species and habitat diversity. This strategy has to be based on additional studies of cerrado dynamics and fire ecology and on continuous monitoring. Furthermore, fire management actions must account for local conditions, since fire behavior is dependent on climatic events that may differ from one region to another. These differences will affect the basic approach to fire management, including how firebreaks are designed, the scheduling of prescribed fires, the circumstances under which fires are allowed to burn, and postfire dynamics in the communities.

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