Forum Article

The Use of Fire in the Cerrado and Amazonian Rainforests of Brazil: Past and Present

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ABSTRACT

Humans have been changing the natural fire regimes in most Brazilian vegetation types for over 4000 years. Natural lightning fires can easily happen in savannas and grasslands, but they are rare in the moist rainforests. Today, anthropogenic fires are frequent in both the fire-adapted cerrado (Brazilian savanna) and the fire-sensitive rainforest. In this paper, I compare two very different biomes concerning their susceptibilities and responses to fire: the Amazon rainforest and the cerrado. I present an overview of their fire history, especially regarding human-made fires for land management, and pull together information about the use of fire by indigenous peoples in the cerrado and the Amazon, as this information is very fragmented. Accordingly, I describe how fire regimes have changed in these biomes over time due to agricultural practices and the consequences of the current altered fire regimes. After European settlement, fire frequency greatly increased in the cerrado, especially related to cattle ranching, and more recently in the more seasonal landscapes in the Amazon. In cerrado natural preserves, however, managers try to keep fire away, but wildfires eventually come and develop into destructive events. Actions to reduce biodiversity loss and environmental deterioration due to inappropriate fire management are necessary and should be very distinct in both areas: in the Amazon they would include the development of policies to stimulate fire-free, small-scale agricultural projects, and in the cerrado, sustainable use of fire for cattle ranching is possible but the regimes must be fitted to local specific features in order to avoid land degradation. In cerrado conservation areas, proper fire management programs based on scientific knowledge and the incorporation of the traditional expertise of indigenous peoples are needed to maintain the biological diversity, to maintain the ecological processes, and to reduce wildfires.

Keywords: Amazon rainforest, cerrado, fire management, fire regimes, indigenous fire use, land uses

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INTRODUCTION

Most Brazilian vegetation types (biomes) are subjected to fires, to a greater or lesser degree. Rainforests, semideciduous forests, dry forests, shrublands, savannas, and grasslands are all presently burned by humans for different purposes and land uses, although the natural potentials for burning the vegetation are very different. Flammability (defined by Phillips [1974] as "the capacity for vegetation to be ignited at flash point") and combustibility ("the capacity to sustain fire and to remain alight" Phillips [1974]) depend on the type, amount, and dryness of fuel, all of which are highly variable among these vegetation types.

According to their associations with fire, Hardesty *et al*. (2005) classified the world's ecosystems as fire-independent, fire-sensitive, and fire-dependent. In fire-independent ecosystems, fire never or very rarely happens either because climatic conditions do not permit it (too dry, too wet, or too cold), or because there is not enough biomass to carry a fire. Fire-sensitive ecosystems are damaged by fire that disrupts ecological processes, kills many individuals, or even eliminates species in such ecosystems that have not evolved under this selective force. In contrast, fire-dependent ecosystems evolved in the presence of periodic or episodic fires and depend on them to maintain their ecological processes; species are fire-adapted, flammable, and fire-maintained, and fires are recurrent.

Although most Brazilian vegetation types do burn periodically, there exist both fire-sensitive and fire-dependent ecosystems (Figure 1). Tropical rainforests, such as the Amazon and the Atlantic forests, are sensitive to fire. Most tropical forest species cannot tolerate burning, and after a few repeated fires, trees are killed, the soil organic matter (which is the nutrient reservoir in tropical rainforests) is incinerated, the structure and floristic composition of the forest change, and the forest shifts to another type of ecosystem: either to a degraded forest or to a savanna-like environment (Borhidi 1988, Cochrane *et al*. 1999, Nepstad *et al*. 2001). However, shifts to another type of ecosystem are not necessarily permanent.

On the other hand, open savannas and well-drained grasslands of the cerrado biome are fire adapted and fire-dependent ecosystems. Cerrado occurs in the central part of the country (Figure 1) where climate is markedly seasonal with high rainfall in the wet season (around 1000 mm or more) and an extended

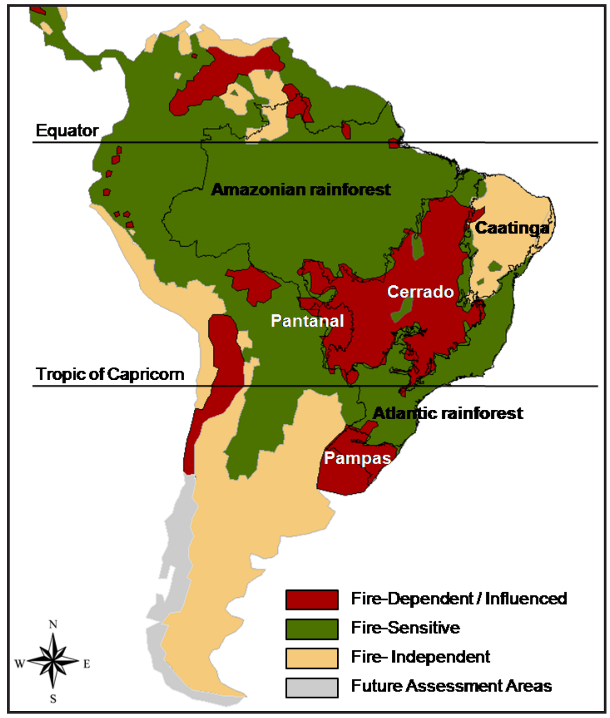

Figure 1. Fire-sensitive, fire-dependent, and fire-independent vegetation in South America, highlighting the Brazilian biomes (Amazon rainforest, Cerrado, Caatinga, Pantanal, Atlantic rainforest, Pampas) (Hardesty *et al.* 2005).

dry season from May through September to October. The rainfall that does occur supports a considerable amount of aboveground biomass (4.9 Mg ha^{-1} to 12.9 Mg ha^{-1}) (Pivello and Coutinho 1992, Castro and Kauffman 1998). The grassy herbaceous biomass becomes especially dry and very flammable in the dry season, and fire outbreaks naturally caused by lightning are common at the beginning of the wet season (Ramos-Neto and Pivello 2000). In addition, pastoralists used to burn cerrado vegetation in the dry season to increase palatable grasses for cattle. Another fire-prone vegetation type also exists in the southernmost part of the country, under a humid climate: the subtropical grasslands or Pampas. This type is probably relict vegetation from a drier climate of earlier periods (late Pleistocene through Holocene) maintained until the present by fire and grazing (Behling *et al*. 2005, Pillar *et al*. 2009).

In this paper, I will present an overview of the history of fire in two Brazilian biomes that have distinct adaptability to fire: the fire-prone cerrado and the fire-sensitive Amazon forest. My objectives are: a) to pull together information about the use of fire by pre-Columbian peoples in cerrado and Amazon regions; b) to examine how fire regimes have changed in these ecosystems through time; c) to assess the consequences of the altered fire regimes; and d) to indicate possible actions to reduce degradation due to inadequate fire management in such ecosystems.

ANCIENT FIRES IN THE CERRADO AND THE AMAZON: EFFECTS ON BIOTAS

The cerrado is a vast, biologically diverse tropical savanna that dominates the Great Plateau of central Brazil, but also occurs dispersed in many patches beyond that core area. The vegetation ranges from grasslands (campo limpo) through several savanna formations (campo sujo, campo cerrado, cerrado *sensu stricto*, according to increasing tree density) to sclerophyllous woodland (cerradão) (Pivello and Coutinho 1996, Furley 1999). This variation may occur due to several causes: soil depth, fertility or water retention capacity, topographic peculiarities that may change microclimate or soil water retention, and human interferences such as burning, selective cutting, or pasturing (Pivello and Coutinho 1996, Furley 1999, Ruggiero *et al*. 2006).

Natural fires due to lightning in the cerrado can easily happen (Ramos-Neto and Pivello 2000). Both the seasonal climate with a marked dry season (typical of the savannas) and the continuous grassy herb layer that constitutes a flammable material when desiccated contribute to recurrent fires (Miranda *et al*. 2002).

Those recurrent fires have been present in cerrado environments for millennia as a key evolutionary force (Hoffman 1999, Simon *et al*. 2009) (Figure 2). As a result, a great number of morphological and physiological adaptations to frequent fires can be found in cerrado vegetation. Typical twisted trees and shrubs have thick corky bark and fruit walls that protect the inside tissues and seeds from high temperatures during the passage of fire (Coutinho 1982, 1990; Cirne and Miranda 2008); many forbs have subterranean woody organs (xylopodia and lignotubers) able to promote quick leaf and flower sprout after fire (Coutinho 1982, 1990); and belowground biomass in the cerrado is two to three times higher than the aboveground biomass (Castro and Kauffman 1998), advantageous strategies in frequently burned environments. Besides inducing flowering in the herbaceous species, fire also increases fruit and seed production as an effect of the synchronized blooming and rise in sexual reproduction. In woody species, high temperatures trigger fruit dehiscence and seed release; still, germination rates increase after fire for a number of fire-resistant species (Coutinho 1980, 1982; Gottsberger and Silberbauer-Gottsberger 2006). Frequently burned cerrado areas tend to become more open and grassy; most of the young trees are killed by fire and the herb layer is favored by ash deposition that brings nutrients to the surface soil (Coutinho 1990, Pivello and Coutinho 1992, Kauffman *et al*. 1994).

Figure 2. A cerrado wildfire, in the Jalapão region, Tocantins State, Brazil. (Photo by Vânia R. Pivello.)

Even the typical cerrado fauna show adaptations to fire: to escape flames, many species have fossorial habits or hide in holes and termite mounds during the passage of fire, and gallery forests and swamps have an important role in offering shelter for several animals during fire (Redford and Fonseca 1986, Coutinho 1990). Grazers and browsers are particularly favored by the improved quality of forage that resprouts after fire, and many birds also benefit from the increase in food availability (grains, fruits, prey) caused by fire. It has been observed that some arthropods (grasshoppers, cicadas, and spiders) and mammals (giant anteater [*Myrmecophaga tridactyla* L.], peccary [*Tayassu peccary* Link.]) may get a darker color after the burn (Coutinho 1990).

Yet considering the strong importance of fire in cerrado evolution, a question about the origin of such biome persisted until recently. Is it a rather recent system that originated from dry forests with some influence of human-made fires (Rawitscher 1951, Eiten 1972), or did the cerrado biota evolve under a particular climate and natural fires (Ledru 2002, Scheeel-Ybert *et al*. 2003, Vivo and Carmignotto 2004, Hirota *et al*. 2010)?

The reconstruction of the cerrado paleovegetation started to be developed after the 1970s, founded on palynological studies and on the analysis of the distribution of charcoal pieces in the soil profiles. Based on pollen and charcoal records, one can say that frequent fires were present in the cerrado much before the arrival of humans in South America around 12 000 years BP (Salgado-Labouriau and Ferraz-Vicentini 1994, Cooke 1998, Ledru 2002), and especially during the Holocene, when periods of much drier climate occurred (Pessenda *et al*. 2001, 2004, 2005). A more recent approach, followed by Simon *et al*. (2009) and based on time-calibrated phylogenies, supports that cerrado plant lineages are strongly associated with adaptations to fire, and that the diversification of the majority of cerrado endemic flora happened about 4 million years BP or sooner, when savannas expanded worldwide and flammable C_4 grasses became dominant. The authors suggest that cerrado plant species originated *in situ* due to the selection of adaptations to resist fire rather than by the dispersal of lineages already adapted to fire. Therefore, based on present knowledge, we believe that the occurrence of frequent natural fires, facilitated by the spread of sun-loving grasses in periods of a drier climate ,have tailored cerrado biota (agreeing with Pinheiro and Monteiro 2010); however, humans certainly contributed to increase fire frequency and to the maintenance of savannas and grasslands in more recent times.

The Amazon moist tropical forest, on the other hand, is very difficult to ignite naturally. If a lightning fire does start in the forest, the high humidity of vegetation and litter will restrict it to isolated trees or to very small patches, and fire intensity usually will be extremely low (Fearnside 1990, Cochrane 2009*a*). Therefore, as fire events have been rare in the evolutionary history of the Amazon rainforest (frequency of 500 yr to 1000 yr), the vast majority of vegetation and fauna species are not adapted to this environmental factor. Plant species are severely damaged by burns even of a low intensity; as species are unable to tolerate high temperatures, understory fires kill some trees, depending on their size class, and reduce forest biomass; seed and seedling banks are depleted; and microclimatic conditions change, favoring the establishment of ruderals and lianas (Uhl and Kauffman 1990, Cochrane *et al*. 1999, Cochrane and Schulze 1999, Cochrane and Laurance 2002, Barlow and Peres 2008, Cochrane 2009*a*). As a result, the forest structure and species composition change dramatically, also changing vital processes such as nutrient cycling, seed dispersal, and the maintenance of biodiversity. Recurrent fires definitely aggravate this process and species may become locally extinct. Fauna may also be indirectly eliminated due to habitat loss (Barlow and Peres 2008, Cochrane 2009*a*).

However, in periods of severe drought, parts of the Amazon biome where there is some climatic seasonality—mainly where it borders the cerrado biome but also in core areas of the Amazon forest—are able to catch fire, especially if the forest structure has been altered by human activities (Figure 3). In fact, it is believed that the real cause of wildfires in the Amazon forest is the synergistic effect of droughts and human activities (Cochrane *et al*. 1999, Nepstad *et al*. 2004, Alencar *et al*. 2006, Nepstad *et al*. 2006, Aragão *et al*. 2007, Aragão *et al*. 2008, Bush *et al*. 2008, Cochrane and Laurance 2008). Authors attribute such dry periods to El Niño events, which change temperatures in the Pacific Ocean and induce droughts in the north of Brazil (Kitzberger *et al*. 2001, Zeng *et al*. 2008), or to minima of solar activity, when solar output is reduced and decreases moisture income from the Atlantic Ocean to the continent (Bush *et al*. 2008), or still to La Niña events, which have an opposite effect of El Niño, decreasing Pacific Ocean temperatures and the humidity in the cerrado region (Instituto Nacional de Pesquisas Espaciais [INPE] database in: www.inpe.br). More recently, authors have also related severe droughts that may lead to fires in the Amazon forest to the Atlantic Multidecadal Oscillation (AMO), a series of alternating periods (decades) of cooling and warming the surface waters of the north Atlantic Ocean (Aragão *et al*. 2008, Zeng *et al.* 2008).

Figure 3. Wildfire in the Amazon forest, south of Tailandia, Pará State, Brazil. (Photo by Mark A. Cochrane.)

Soil charcoal has been found in the Amazon forest region and provides a good indication of fire occurrences. From the end of Pleistocene through the whole Holocene, at least two periods of forest retreat concomitant with the advance of savannas and grasslands might have occurred: between 11 000 yr to 10 000 yr, and between 8000 yr to 4000 yr BP (Pessenda *et al*. 2001, 2004, 2005). Pieces of paleocharcoal found in the region are dated to the last 9000 years when primitive human groups probably were already around (Sanford *et al*. 1985, Bush *et al*. 2008). It is believed that pre-Columbian humans retarded the advance of forests over savannas during the moister periods by frequently setting fire in the vegetation. By 1000 years BP, large-scale burning in the Amazon region denoted intense human activity (Fearnside 1990).

FIRE MANAGEMENT BY INDIGENOUS PEOPLES IN THE CERRADO AND AMAZON FOREST

Semi-nomadic "land managers" were actively using fire in the cerrado and in the rainforest borders by 4000 yr to 5000 yr BP (Fiedel 1992, Prous 1992). That management practice was passed to their descendants and, consequently, the use of fire was very widespread among most indigenous groups in Brazil, especially those belonging to the linguistic families Jê (e.g., Xavante, Krahô, Kayapó) (Maybury-Lewis 1984, Anderson and Posey 1985, Posey 1985, Mistry *et al*. 2005, Melo 2007), Aruák (Silva 2009), and Tupi-Guarani (e.g., Guarani, Ka'apor, Guajá, Tembé) (Godoy 1963, Balée 1993).

By the time the Portuguese arrived in Brazil (1500 AD), the country was populated by more than a thousand different indigenous groups, estimated at 1 to 5 or even 10 million people (FUNAI 2010). Some groups, as the Kayapó, settled big villages of more than 70 000 people, managing resources in a sustainable way. After the European colonization, the indigenous peoples were reduced to a tenth, mostly due to diseases contracted from Europeans (Bush *et al*. 2008, Nevle and Bird 2008). Today, there are about 215 ethnic groups, living mostly in the indigenous reserves in the north of the country (FUNAI 2010, IBGE 2010). That extreme reduction in the indigenous populations most probably was the reason for a substantial decrease in fire activity after the European colonization up to the year 1750, as evidenced by charcoal records (Bush *et al*. 2008, Nevle and Bird 2008).

Specific studies on the use of fire by Brazilian indigenous groups are rare, and the existing information, mostly coming from anthropological studies, is fragmented. Nevertheless, the available information shows that Brazilian indigenous peoples used fire for a number of reasons: to clear pathways and the surroundings of their houses to facilitate walking; to open areas for cultivation; to kill or drive away pests and snakes; to eliminate wastes; to attract and drive game during hunting; to stimulate grass regrowth, flowering, and fruiting of some plants; to attract game that fed on fresh herb and fruits; and to collect honey. They also used fire in their wars and rituals, for signaling, and for shifting cultivation (slash-and-burn) (Gross *et al*. 1979; Posey 1984, 1985, Anderson and Posey 1985; Hecht 2009; Silva 2009). None of the indigenous groups in Brazil were pastoralists; they were hunter-gatherers and land-managers who used fire as an important tool to manipulate the environment according to their needs. Some groups who lived and still live in the forest-savanna borders, and who are better known to scientists, such as Kayapó, Tupi-Guarani, Krahô, and Bororo, practiced very refined fire management methods. The Kayapó, for example, recognized and managed more than 40 types of forests, savannas, and grasslands. They used fire to create islands of resources (orchard patches) where they planted several species of fruit trees and other useful plants. Fire was used to make firebreaks around these orchards to protect them from accidental burns. Specific fire regimes were applied to stimulate the flowering and fruiting of some species or to control plant diseases. Cool burns during the first spring rains were also made to fertilize the soil through the ashes deposited on soil surface, without damaging the plants. Therefore, mosaic burnings in savannas were used to increase the diversity of useful plants and resources (Posey 1984, 1985; Anderson and Posey 1985, 1987; Hecht 2009).

Another use of fire was for shifting cultivation. The practice was adopted by most groups of indigenous peoples and seems to have appeared independently in several tropical ethnic groups (Adams 2000). The task was careful and detailed: burns were usually made in small patches; they first opened gaps in the forest by cutting most trees, also calculating the way to fell them in order to leave open corridors where they planted edible roots and bulbs (cassava, sweet potato, etc.). After a couple of months, when the felled trees were drier, they burned them, controlling the fire temperature so as to not damage the plantation. The resulting ashes fertilized the soil and maintained a high productivity of the domesticated plant species for 2 to 3 years ("new fields"). After that, the field was abandoned for some decades to recover (fallow period). However, people still visited the "old fields" for several years (even decades) to collect fruits. The cultivated plots (*roças*) were of different sizes, and the natural vegetation around them was left intact to facilitate forest regrowth in the plots after abandonment (Posey 1985, Leonel 2000, Peters 2000, Pinto and Garavello 2002, Pereira 2004, Hecht 2009). With this kind of rather sophisticated agroforestry system, the indigenous peoples deliberately directed forest succession according to their needs.

There is also evidence that indigenous groups from the Amazon basin had been using fire since pre-Columbian times to create *terra preta,* a very dark, organic, and fertile soil with a high charcoal content (Glaser *et al*. 2001, Glaser 2007). To make this kind of substratum, they used a technique named slash-and-char in which, similar to slash-and-burn, forest patches were cleared but burned at relatively low temperatures to create charcoal (Woods *et al.* 2009).

Whatever the reason, the use of fire by indigenous peoples was very careful and accurate. The objectives for burning, the burning site, and the fire behavior were well defined and determined the fire regime to be adopted. Based on several ecological indicators such as river cycles, clouds, wind direction, level of rivers, cycles of key plant and animal species, the elders decided when and how to burn, and the leaders announced the decision to the male group, denoting a clear social control over the activity and a precise way to keep their resources (Posey 1984, 1985; Anderson and Posey 1985; Pivello 2006).

CURRENT FIRES IN THE CERRADO AND AMAZON FOREST

Natural fires in Brazil are caused by lightning; relevant volcanic activities in the country are virtually none. Still, Brazil is one of the places in the world with the highest incidence of lightning, and the numbers are increasing fast: from 2005 to 2008, the number of lightning strikes more than doubled, probably due to climatic events such as the La Niña phenomenon and global climate changes (ELAT-INPE 2009). Ramos-Neto and Pivello (2000) were the first to demonstrate that lightning fires in the cerrado region are frequent: 91% of the 45 fire events registered at Emas National Park from June 1995 to May 1999 were caused by lightning during the wet season or in the seasonally transitional months when heavy storms occur. In their four-year survey, every anthropogenic fire registered happened in the dry season and burned extensive areas, contrasting with the natural fires that burned small patches and were rapidly extinguished by rain. Very similar patterns were later found by Medeiros and Fiedler (2004) in the Serra da Canastra National Park, and by Fiedler *et al.* (2006) in Chapada dos Veadeiros National Park.

However, the great majority of wildfires both in the cerrado and in the Amazon region are caused by human ignition. Today people mainly use fire to remove the natural vegetation to install crop cultures or pastures; when performing the shifting cultivation; or to manage their agricultural crops, either to burn residues or to stimulate the regrowth of herbs to feed cattle in the dry season. Accidental fires that turn out to be large wildfires are common due to these practices, and arson fires are not uncommon.

The practice of shifting cultivation was transmitted by indigenous peoples to local peasants (*caboclos*) after European colonization. However, the knowledge was partially lost and fire management was no longer so careful and precise. In order to be sustainable, shifting cultivation demands low population densities and large areas to allow an adequate fallow period in a rotating system. But *caboclos* have a sedentary lifestyle, and their agricultural lands are restricted to relatively small areas. Therefore, they burn large plots at each time in high frequency. The great majority (85% to 90%) of the existing indigenous peoples who presently live in the federal indigenous reserves (ISA 2010) became semi-sedentary or sedentary and have also had to adapt their fire management procedures to their relatively small reserves. Signs of soil degradation in these reserves can be observed (Gross *et al*. 1979).

The use of fire to replace native vegetation by agriculture is widespread both in the cerrado and the Amazon. The cycle usually starts with the removal and burning of the vegetation; part of the trees is transformed to charcoal, and the rest of the vegetation turns into ash and is used as soil fertilizer. The cleared area is then transformed into planted pasture, subsistence cultures, or industrialized grain crop plantations, mostly of soybean. In industrial agriculture, intense fires are initially used to clear vegetation; however, during the crop production cycle, fire is occasionally used to burn crop residues (Ratter *et al*. 1997, Eva and Lambin 2000, Ferreira *et al*. 2005, Morton *et al*. 2006, Cochrane 2009*a*, Aragão and Shimabkuro 2010).

Cattle were introduced in the cerrado region during colonial times (Barcellos *et al*. 2001), and since then, cattle ranching became a common practice in the native savannas and grasslands. In the extensive beef-cattle production, annual or biennial fires are commonly applied to stimulate grass regrowth in the dry season when forage is in short supply. Most cattle ranchers do not make firebreaks and the fire spreads to large areas. About 40 years ago, beef-cattle production in the cerrado became large-scale and directed toward exportation. On such ranches, the native vegetation is totally removed, highly productive African grasses are planted, and fire is occasionally used to manage specific problems.

As in the cerrado, the production of beef cattle has been the main reason for burning the Amazon rainforest. The Portuguese colonizers introduced cattle in the Amazon in the seventeenth century, but large-scale production started in the 1900s (Perin *et al*. 2009). From 1997 to 2007, the number of animals increased about 80% and the area for pasture more than doubled (IBGE 2009). Still, Aragão and Shimabukuro (2010) found an increased trend in fires in 59% of the areas with decreased deforestation trend. Although they were not able to separate fire types, this increase could have been due to cattle grazing. Pastures are not sustainable in the Amazon region, and when the soils are exhausted, cash-crop farmers buy the land to introduce intensive agriculture, usually soybeans (Ferreira *et al*. 2005, Cochrane 2009*a*).

The conversion of the Amazon forest into pastures or intensive agriculture is usually preceded by logging. Roads are opened into the forest to permit the entering of loggers, and the extraction and transportation of timber leads to the opening of more roads and trails. Logging activity itself does not require fire; however, the extraction of large trees opens the forest canopy, decreases the local moisture, and highly increases the forest susceptibility to wildfires that come from pastures or slash-and-burned areas nearby (Fearnside 2005, Balch *et al*. 2009). This kind of event was of great concern in 1997 and 1998, dry years that were subjected to the El Niño effects, when huge areas in the south of the Amazon River were burned (Cochrane 2009*b*). Similarly, the AMO-driven 2005 Amazonian drought resulted in numerous fires (Cox *et al*. 2008). Logged forests that are no longer profitable are usually replaced by pastures; and for that, the remaining forest is totally burned. After installing the pasture, fire is periodically used to kill woody regrowth and to maintain some fertility in the soil for some years.

CONSEQUENCES OF FIRE ALTERED REGIMES AND THE LACK OF A FIRE MANAGEMENT POLICY

As in many places in the world, current land use and agricultural practices have considerably changed fire regimes in the cerrado and Amazon regions compared to pre-Columbian times (Figure 4)—a result of too much fire, too little fire, or the wrong fire regime (Shlisky *et al*. 2009). The wrong fire regime leads to soil degradation, biological invasions, and overall biodiversity loss.

Human-caused fires in most cerrado fragments are happening at a much higher frequency than in the past, and the fires are hotter because people perform burns in the dry season, in contrast to wet-season natural fires (Ramos-Neto and Pivello 2000). This new regime favors herbaceous species and encourages the maintenance of the open cerrado physiognomies, or it may cause land degradation (Pivello and Coutinho 1992, 1996). However, the opposite situation happens in cerrado conservation areas where fires are usually not allowed

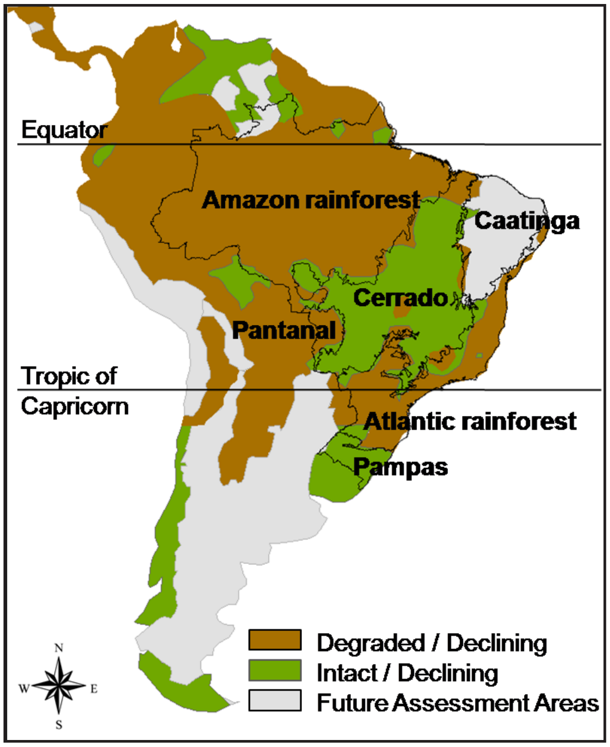

Figure 4. Presently altered fire regimes in South America, highlighting the Brazilian biomes (Amazon rainforest, Cerrado, Caatinga, Pantanal, Atlantic Forest, Pampas) (Hardesty *et al.* 2005).

and there are no fire management programs based on prescribed burnings to maintain the savanna natural biological cycles. As a result, fuel builds up, boosting the risk of wildfires, and when an accidental fire occurs, it is much more severe, burns large extents, and threatens the native fauna and cerrado endemic species (Pivello and Norton 1996, Pivello 2006).

In the Amazon forest, the return interval of a natural fire was probably about 500 yr to 1000 yr in the past; now fire returns every 5 yr to 10 yr in a particular landscape in eastern Pará, for example (Cochrane 2009*a*), caused by escaping agricultural fires. These return intervals may appear in other regions, but that has not yet been determined. Such short intervals may either convert the forest to a savanna (Cochrane *et al*. 1999), or totally degrade it, and consequently, devastate the biodiversity and ecological services.

The combination of human activities and dry years increases considerably the number and extent of wildfires in both the Amazon and cerrado regions. This is the case of the present year (2010), when the number of fire spots detected by satellite images and registered by the Instituto Nacional de Pesquisas Espaciais (INPE) from January to August was about four times higher than in the same period of the previous year (Figure 5). Comparing the fire

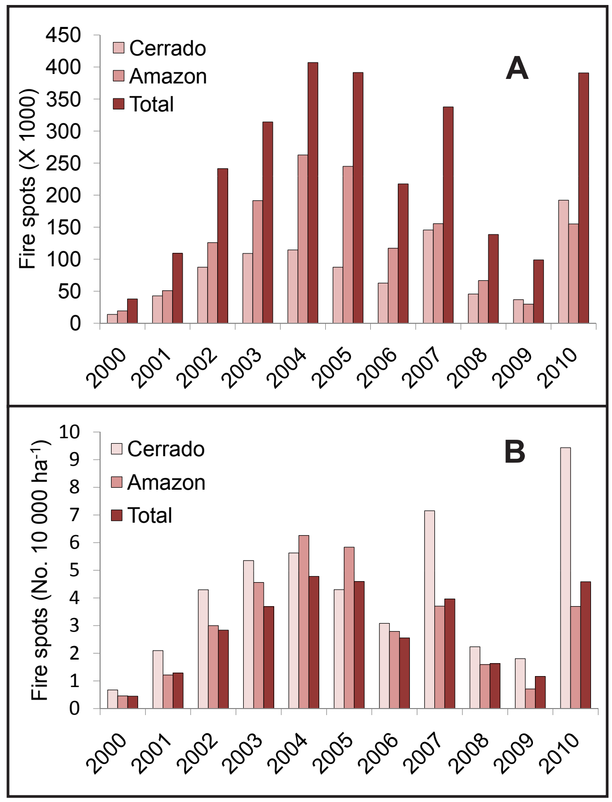

Figure 5. A = number of fire spots detected by satellite images and registered by INPE (Instituto Nacional de Pesquisas Espaciais, São Paulo, Brazil) in the Amazon forest and cerrado from January to August of 2000 to 2010; B = the same number of fire spots normalized by the respective areas of the Amazon forest and cerrado (Amazon area = 419.6943 million ha; cerrado area = 203.6448 million ha, according to the Instituto Brasileiro de Geografia e Estatística- IBGE, http://www.ibge.gov.br). Numbers of fire spots come from all the satellites with optic sensors that operate in the medium-thermal band of 4 µm received by INPE, including series NOAA-AVHRR, series MODIS-TERRA, series MODIS-AQUA, GOES-10 and GOES-12, and MSG-2, at morning, afternoon, night, and dawn (http://www.dpi.inpe.br/proarco/bdqueimadas/). The values from 2007 onwards may be somewhat underestimated because NOAA-12 was decommissioned that year.

spots in the cerrado and Amazon forest in the same period (from January to August) in the last ten years, one can notice that other dry years with very high numbers of fire foci occurred, as in 2004/2005 or 2007; however, the incidence of fire spots per area in 2009/2010 has been comparatively high in the cerrado (Figure 5). Some cerrado protected areas, such as Emas National Park (area = 1330 km^2), Serra da Canastra National Park (area = 1978 km^2), and Chapada dos Guimarães National Park (area = 326 km^2), were severely burned in August 2010 (see example of Emas National Park in Figure 6). According to França (2010), 91 %, 42 % and 35 % of their areas burned, respectively. In September 2010, catastrophic fires occurred in other cerrado national parks, such as Chapada dos Veadeiros (77 % burned), Araguaia (56 % burned) and Brasília (36 % burned).

The states of Mato Grosso and Pará register the highest numbers of fire events in the Amazon forest. Those areas are mainly located in borders with the cerrado, where the climate is more seasonal and human activity is more intense ("arch of deforestation"). In the cerrado biome, fires are also more abundant in the states of Mato Grosso, as well as in Tocantins, where most of the remaining large cerrado patches are located (Figure 7). These frequent fire episodes demonstrate the lack of structure and planning related to accidental fires in the country, especially during dry years when wildfire incidence is much higher than usual. These fires also highlight the need for a huge program of education and awareness directed toward the agriculturalists, and followed by effective inspection and application of penalties in cases of inappropriate fire usages.

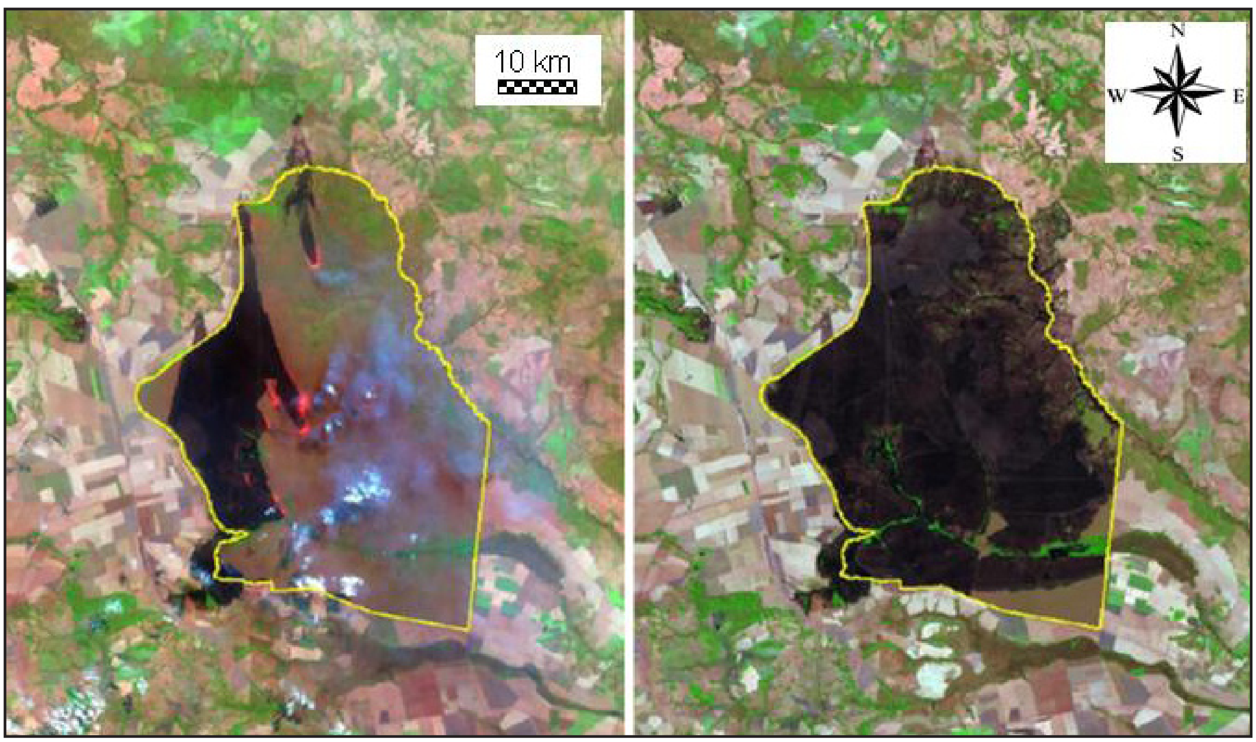

Figure 6. Satellite images of the Emas National Park (17°49'–18°28' S and 52°39'–53°10' W, Goiás state, Brazil) from August 2010 showing the beginning of the fire (A = ResourceSat/Liss3, orbit/point 324/90, 13 August 2010) and when it had already extinguished and burned 91 % of the park area (B = Landsat-TM5, orbit/point 224/72 and 224/73, 27 August 2010). (Sources: Instituto Nacional de Pesquisas Espaciais; França 2010)

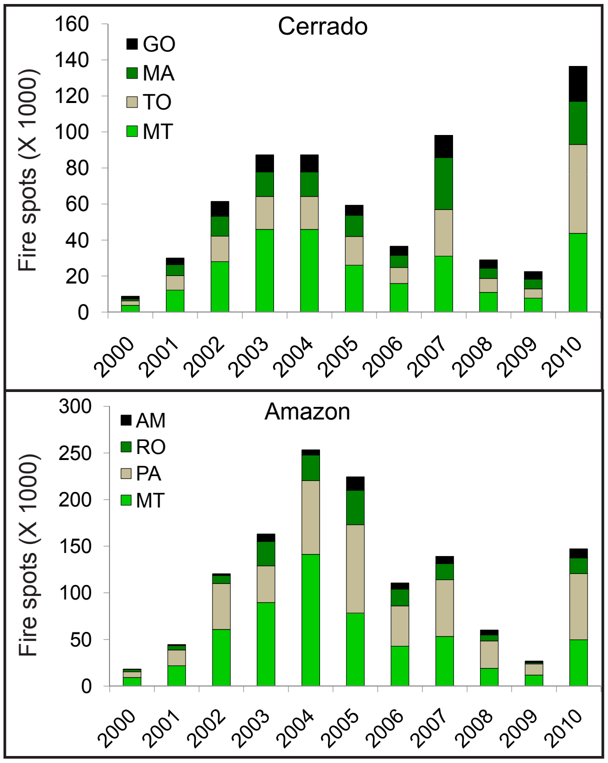

Figure 7. The top four states in areas covered by the Brazilian Amazon forest and cerrado with the highest numbers of fire sources registered from January to August in the last ten years (2000 to 2010) (AM = Amazonas; GO = Goiás; MA = Maranhão; MT = Mato Grosso; PA = Pará; RO = Rondônia; TO = Tocantins).

Wildfires caused by inappropriate agricultural practices are also the main sources of greenhouse gases emissions, because in Brazil, such emissions are mostly due to the burning of native vegetation. Although today the cerrado deforestation rate is twice that of the Amazon forest, both biomes make a similar contribution to carbon emissions, even though the Amazon forest aboveground biomass is much higher. Barlow and Peres (2008) point out that biomass burning is one of the few parameters of climate change that can be directly controlled. Therefore, social and economic policies to stimulate small-scale agricultural projects where fire is not applied should be developed for the Amazon region.

In the cerrado region, cattle ranching can be sustainable if appropriate fire regimes are followed and wildfire prevention measures are taken. Still, cerrado conservation areas would benefit from controlled management fires under proper regimes, as fire is part of cerrado evolution and maintains relevant ecological processes and the native biodiversity. Concerning carbon emissions, studies demonstrate that when the native vegetation is not suppressed or replaced by crops, all the emissions of a burn will be re-assimilated after one year due to the rapid and vigorous regrowth of cerrado plants (Santos *et al*. 2003, Grace *et al*. 2006). Thus, for conservation purposes, controlled cool fires every 4 yr to 6 yr in a mosaic arrangement would reduce fuel and avoid wildfires in cerrado (Pivello and Coutinho 1992, Pivello and Norton 1996, Ramos-Neto and Pivello 2000, Pivello 2006). This strategy must be complemented with effective inspection by fire personnel in the dry season, educational programs for the agriculturalists, and constant monitoring of the native plant and animal communities.

In conclusion, fire can and must be used in fire-adapted ecosystems to maintain ecological processes and biodiversity, provided that the adequate regimes are applied, or in the strict traditional sustainable approach. Fire management programs for cerrado protected areas should be based on scientific knowledge and also take advantage of the remarkable empiric knowledge of the traditional peoples.

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