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Fire frequency and area burned in the Roraima savannas of Brazilian Amazonia

Reinaldo Imbrozio Barbosa
INPA/CPEC (Roraima)
C.P. 96
69301-970 Boa Vista, Roraima
Brazil
+55-(95)-623 9433
reinaldo@inpa.gov.br

Philip Martin Fearnside
INPA/CPEC
C.P. 478
69011-970 Manaus, Amazonas
Brazil
+55-(92)-643 1822
pmfearn@inpa.gov.br

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Abstract

Estimates were made of the percentage of area burned and the fire frequency in different ecosystems of non-anthropic savannas located in the north and northeast portions of the State of Roraima, Brazil. Three years of observations (June 1997 to May 2000) indicated that the mean percentage of area burned annually, weighted for all ecosystems, was 38 ± 12 (SD) %. The mean frequency of fire (number of years for an area to burn again) was 2.5 years. Both parameters are dependent on the type (structure) of vegetation, the altitude of the savanna and the climatic state (dry, wet or normal) of the year of the observation. Using values for two-month periods over the three year time series (n=18), a simple regression model to forecast percentage area burned was developed for Sg savannas (grassy-woody savanna; "clean field" and "dirty field" types), using as the independent variable the daily mean precipitation. The proposed model explains 66% of the reported cases. These results are the first developed for savannas in the Amazon region and are directly applicable to calculations of greenhouse-gas emissions from burning in this ecosystem type.

Keywords: Amazonia; Burned area; Fire frequency; Roraima; Savannas

1. Introduction

Amazonia plays an important role in the maintenance of the world carbon balance (Fearnside, 1997; Houghton et al., 2001; Nascimento and Laurance, 2002). Amazonia's carbon storage potential gives great importance to land-use changes in this region because disturbances of the natural landscape can increase atmospheric carbon and affect global biogeochemical cycles (Seiler and Crutzen, 1980; Houghton et al., 1983; Greenberg et al., 1984; Crutzen and Andreae, 1990; Houghton, 1990; Setzer and Pereira, 1991; Fearnside, 1996). Biomass burning produces significant amounts of trace gases, such as methane (CH_4) and nitrous oxide (N_20), which contribute to global warming and other global atmospheric changes. Net emissions of carbon dioxide (CO_2) can also be affected.

Forest ecosystems receive the attention of most of the scientific studies conducted in Amazonia because forests represent the largest landscape in the region. However, Amazonian savannas represent a significant portion of the area of terrestrial systems, and, in the same way as the forests, savannas are rapidly being converted for agriculture and ranching and is exposed to recurrent burning in thousands of km^2 of the remaining original (non-anthropic) ecosystems. This transforms the savanna ecosystems into an important terrestrial source of greenhouse gases (Seiler and Crutzen, 1980; Ward et al., 1992; McNaughton et al., 1998; Hoffa et al., 1999).

Of the studies that have been done on a large scale in Brazil on emission of gases by savannas, most are limited to evaluations of the savannas of the country's center-west region, close to the area known as the "Arc of Deforestation" (Barbosa, 2001). Of these, only two studies (Schroeder and Winjum, 1995; Fearnside, 1997) attempted to estimate the potential emission of this Brazilian ecosystem despite the high uncertainty or outright lack of values for some of the parameters needed for the calculations, such as the extent of the area burned annually and the frequency of the passage of the fire. These two factors are important in calculations of the storage and release of carbon in savanna areas (IPCC/OECD, 1994).

Acceleration of burning frequency can result in depletion of carbon and nitrogen stocks in the soil, eventually leading to reduced grass productivity (Kauffman et al., 1994; Scholes and Walker, 1993 cited by Sampson et al., 2000, p. 207). Burn frequency has increased in the cerrado areas of Brazil's center-west region as a result of more intense management of these ecosystems for cattle grazing (Coutinho, 1990, pp. 87-88). Climatic changes such as increased frequency of El Niño events, leading to dry years in Amazonia, could contribute to future increases in burning frequency.

Due to the almost complete lack of studies on this subject, most calculations of greenhouse-gas emissions use unreferenced values (probably guesses) for fire frequency (*e.g.*, Hao et al., 1990), or site a source that leads to one of these unreferenced values. The values put forward by Hao et al. (1990), for example, are used in subsequent estimates (*e.g.*, Scholes and Andreae, 2000) and as IPCC default values (IPCC, 1996, p. 4.64). Remote sensing is used to overcome the inherent deficiencies in this type of calculation. However, the interpretation difficulties associated with this method are also large because burn scars in savannas are visible for only a short period (in contrast to burning associated with deforestation), hindering measurement through remote sensing. It is possible to count the number of fires ("hot pixels"), but not to estimate the size of the burned area without an excessive amount of error (Kaufman et al., 1990; Robinson, 1991). Progress has been made in perfecting sampling methods using the AVHRR sensor with verification of the precision through LANDSAT-TM and/or SPOT images for determining burned areas in central-African savannas (Barbosa et al., 1998; Barbosa et al., 1999a; 1999b; Pereira et al., 1999) and in Brazilian cerrados (Brazil, MCT, 2002 citing Krug et al., 2001; see also Krug and dos Santos, 2001). However, especially in the case of the studies used in Brazil's preliminary inventory of greenhouse gases (Brazil, MCT, 2002), the number of LANDSAT images associated with the "hot spot" (fire pixel) data from the AVHRR sensor was insuficient to estimate area and frequency of burning in the non-anthropic Brazilian cerrados without an excessive amount of uncertainty. An estimate for a small area of cerrado has recently been done using LANDSAT imagery by itself, but without a means of extending the estimate to the cerrado area as a whole (Krug et al., 2004).

The present study has the objective of estimating the percentage of burned area and the frequency of burning in non-anthropic Amazonian savannas through on-the-ground sampling using the primary and secondary highways that cut through the largest block of continuous savannas of the Brazilian Amazon, located in the State of Roraima. The study covered "original" ecosystems (non-anthropic remnants), "anthropic" ecosystems (agriculture and ranching) and "other ecosystems" that are intermingled with the local savannas (*e.g.*, forest islands).

2. Study area

The study area is located in the north-northeast area of the State of Roraima, in the northernmost portion of the Brazilian Amazon – approximately between 2° 30' N and 5° 0' N and 59° 30' W and 61° 30' W (Figure 1). This landscape is an enormous mosaic of savanna ecosystems that are a part of the "Rio Branco-Rupununi Complex", which covers parts of Brazil and Guyana (Eden, 1970; Sarmiento and Monasterio, 1975). Its components range from low-altitude grasslands (< 100 m) to arborous types at higher altitudes (> 1000 m). It is the largest continuous block of savannas in the Amazonian Biome (± 40,000 km^2). The climate of this area is Awi under the Köppen Classification (Lameira and Coimbra, 1988), with 1100-1700 mm of annual precipitation and 100-130 days with rain per year (Barbosa, 1997). The driest months are between December and March (± 10% of the annual precipitation) and the peak of the rainy season is between May and August (± 60% of the annual precipitation). The relief that supports this landscape increases in altitude as one moves from the center-south to the north-northeast, beginning at approximately 80-100 m in the area of the Boa Vista Formation, increasing in the Surumu Formation and remaining in the 250-900-m range as one approaches the high-altitude (> 1000 m) areas of the Roraima Group (Brazil, Projeto RADAMBRASIL, 1975).

[* * * Figure 1 here ****]

3. Ecosystems studied

Characterization of the ecosystems in this study followed the Brazilian vegetation classification system (Brazil, IBGE, 1992), together with the definition adopted for Central Brazilian savannas (Coutinho, 1978; Ribeiro and Walter, 1998). This characterization is important because the dynamics of fire in each ecosystem is different, provoking unequal effects in the area burned and in the fire frequency. The ecosystems (original and transformed) investigated in the present study are presented in Table 1.

[* * * Table 1 here ***]

4. Sampling methodology

4.1. Sampling Transect

The total area burned annually and the frequency of burning of each ecosystem were represented through periodic observations along a triangular sampling transect covering a linear distance of 540.1 km. The transect cuts through all of the vegetation types defined above (see Figure 1). Nine points formed the basis for alignment of the transect: Point 0 (initial) - close to the city of Boa Vista in the Rio Branco valley (2° 47' 39" N; 60° 39' 59" W), Point 1 – in the Tacutu-1 River valley (3° 18' 40" N; 59° 56' 50" W), Point 2 - in the Tacutu-2 River valley (3° 48' 4" N; 59° 44' 14" W), Point 3 - Raposa/Serra do Sol Indigenous Land (4° 10' 42" N; 60° 31' 36" W), Point 4 – in the Cotingo River valley (4° 24' 13" N; 60° 20' 57" W), Point 5 – in the Surumu River valley (4° 11' 38" N; 60° 47' 31" W), Point 6 - São Marcos Indigenous Land (4° 13' 51" N; 61° 0' 56" W), Point 7 – in the Uraricoera River valley (3° 27' 49" N; 60° 54' 39" W) and Point 8 (endpoint) - city of Boa Vista in the Cauamé River valley (2° 52' 9" N; 60° 41' 50" W).

In the first passage along the transect (June-July 1997: rainy season and without burning) we determined and recorded the limits of each ecosystem (original and transformed) based on the number of kilometers traveled by the vehicle used during the whole study. The structural variations among the original systems studied were defined based on the crown cover of the arboreal individuals (Table 1). Because it would be impractical to measure each individual along the 540.1-km transect, we classified the savannas based on our personal experience in visual observation of the general aspect of these vegetation types. We considered the original savannas to be all of the landscapes where the visual appearance of the cover was in accord with the definition of IPCC/OECD (1994), in other words,"... *with continuous grass cover, occasionally interrupted by trees and bushes..."* under different densities. Both “other” and “anthropic” ecosystems were identified within the “savanna” and “steppe-like savanna” great groups, but burning in these areas was not counted, as this has been the subject of a separate study (Barbosa and Fearnside, 1999).

With the linear total (in km) corresponding to each ecosystem, it was possible to infer the burned area (%) and the frequency of the fire for each ecosystem through the quantification of the linear kilometers reached annually by the fire. This was important to avoid the whole area of savannas being considered a block that suffers the impacts of the fires equally, independent of the climatic type of the year (normal, dry or humid), the vegetation type or the geographical location of the site.

4.2. System of measurement

The transect was driven by car every 60 days in the rainy season and monthly in the dry season, during three years from June-July 1997 to April-May 2000, totaling 12,962.4 km of transect in 24 trips. On each trip a log was made of the initial and final number of kilometers traveled and of the burned areas on each side of the highway. Occasional fires in small areas along the edge of the highway were discarded and the linear distances were only used where the landscape had suffered burning over a long distance, independent of the observer being able to see the entirety of the portion of the burn that extends away from the road. In this method we assumed that each side of the highway had independent fire behavior, although there is a probability of the fire moving across the highway because some burning plant material is carried by the wind. At the end of each measurement we computed an average for each vegetation type in each period.

With each passage along the transect we made a correction of the values recorded for distance, using as a reference the first sampling done in the rainy period (June-July1997). This was necessary in order to avoid distortions due to the tires of the vehicle having different air pressure and different amounts of wear on each trip and because of the expansion of the tires due to the varying temperatures (environmental and material) over the course of the sampling period. A test done before the second sampling demonstrated that these factors could influence the measurement by up to 3 km over the course of the transect. To lessen this effect, verification points were established to allow calibrating the measures obtained on each trip. The number of kilometers traveled was recorded in units of 0.1 km.

4.3. Treatment of the data

To obtain an overall average of burned area and of fire frequency for the three years of observation, as recommended by the IPCC (1997), we used a weighting system based on the individual average for each year, considered the proportion of years classified as dry, humid and normal. This took advantage of our observations in years classed as “El Niño” (1997/1998), “La Niña” (1998/1999) and “normal” (1999/2000). We used measurements of annual precipitation between 1966 and 1999 at the Meteorological Station of Boa Vista to determine how many years were below one standard deviation of the mean (dry years), above one standard deviation (humid years) or within one standard deviation (normal years). We estimated that the distribution of these climatic characteristics for the current period would be 18.2% for years considered to be dry, 21.2% for humid years and 60.6% for normal years. These values represent approximately the proportions of a normal distribution for data collected systematically (Zar, 1974, pp. 73-76).

All of the data were grouped into two-month periods representing climatically similar intervals: June-July (peak of the rainy season), August-September (end of the rainy season), October-November (between seasons), December-January (beginning of the dry season), February-March (peak of the dry season) and April-May (beginning of the rainy season). This set of two-month periods totaled 18 (n) values distributed over the three years of data collection. Graphs of the dynamics were plotted for the burning (% area burned), and the fire frequency was calculated in each of the ecosystems starting from the overlapping of values over the sample period. Finally, a simple regression model was derived to estimate the percentage (%) of burned area in the Sg (clean field + dirty field) ecosystem, based on precipitation data obtained from the Meteorological Station of Boa Vista.

5. Results

5.1. Burned area

The weighted mean percentage of area burned annually for all the original ecosystems of “savanna” and “steppe-like savanna” studied in Roraima was 38 ± 12 (SD)% (Table 2). The absolute values pointed to an accentuated variation in the 1997/1998 (dry) biennium (53%), in comparison with 1998/1999 (wet) (30%) and 1999/2000 (normal) (36%). The steppe-like savanna ecosystems (high altitude) had the highest mean area burned annually (46 ± 21%), followed by the low- and mid-altitude savannas (35 ± 9%). Individually, the vegetation types with the lowest densities of trees (grassy-woody) of the steppe-like areas had the largest values for burned area: Tg–clean field (85 ± 6%) and Tg–dirty field (57 ± 14%). The vegetation type with the smallest individual value was the type with the highest crown cover of trees in the areas with low and middle altitudes: Sa (27 ± 17%).

[* * * * TABLE 2 here*****]

Of the total area burned annually, 90.9% occurred between October and March (October-November = 23.3%; December-January = 39.1%; February-March =

28.6%). The remainder occurred in August-September (7.1%) and April-May (2.1%), with June-July having no incidences of burning (Table 3; Figure 2).

[* * * * TABLE 3 here****]

[* * * FIGURE 2 here ****]

5.2. Frequency of burning

The individual values for each biennium indicated that almost all of the locations were only reached by fire once (1997/1998=99.6%; 1998/1999=99.6%; 1999/2000=98.4%) in every sampled year (Table 4). The recurrence of fires within a given year was 0.4% (1997/1998), 0.4% (1998/1999) and 1.6% (1999/2000). Of the total area (weighted average) burned in the three sampled years, 56% burned only once. The remainder was distributed among the areas that burned two (34.3%), three (9.1%) or four (0.6%) times. This means that the average interval between one-time fire events was 1.8 years; the interval between occurrences of two burns in succession was 2.9 years, while three-burn sequences occurred once every 11 years and four-burn sequences once every 159 years. These values imply that the mean time of recurrence of fires in a given area for all the original ecosystems studied was 2.5 years (30 months).

[****TABLE 4 here ****]

On average, 70-80% of the areas burned in one year are not affected by new fires the following year (Table 5). Only 20-30% of the burned areas repeat the same place as the previous year.

[****TABLE 5 here ****]

5.3. Burned area × precipitation (regression model)

Precipitation data from Boa Vista (1997 to 2000) have a strong association with the percentage of area burned in the Sg ecosystem (clean field + dirty field), which includes the area surrounding that city (Figure 3). A regression model using data from two-month periods explains 66.2% of the variance in percentage area burned based on the average daily rainfall (mm/day) in the same two-month period (Figure 4):

$$Y = 11.801 - 4.254 \ln(X)$$

Where Y = percentage (%) of burned area in the two-month period and, X = daily mean precipitation for the same period ($mm.day^{-1}$)

[* * * * Figure 3 here ****]

[* * * * Figure 4 here ****]

6. Discussion

6.1. Burned area

The weighted average of 38% (27-85%) for total percentage area burned annually determined in this study for Amazon savannas in Roraima is similar to the 40% value used by Seiler and Crutzen (1980) for savannas worldwide based on the work of Deschler (1974) for African savanna between 5^{o} N and 12^{o} N and of Fearnside (1978) for Amazonian pastures. However, the value is much lower than the 75% suggested by Menaut and Cesar (1982) and used by Hao et al. (1990) and Hall and Rosillo-Calle (1990) as the average for the African savannas. Later this number was revised to 50% in Hao and Ward (1993) and Hao and Liu (1994) and used as the overall average by different authors in the early 1990s for calculating emissions of gases from biomass burning in savannas in the tropics as a whole. Although data of Lavenu (1982, 1984), cited by Menaut et al. (1991), reported more conservative estimates (25-49%) in studies using LANDSAT imagery of the Sahelian Zone of the Ivory Coast, the 75% value was still used in some studies. Our study also found some high values for low-biomass ecosystems (*e.g.*, 85% for Tg–clean field). This serves to reinforce the need to associate the results of burned area with the respective vegetation types in order to avoid misunderstandings arising from use of a single value for all savanna ecosystems.

The first attempts to distribute the estimates among different types of ecosystems were made by Delmas et al. (1991) and Menaut et al. (1991) in spatial analyses of the total biomass burned in savannas in Africa (10-70%). Scholes (1995), in an evaluation of greenhouse-gas emissions in southern Africa, also distributed his evaluation among vegetation types, ranging from semi-desert (± 0.1%) to humid ecosystems (± 53%). Recent studies by Barbosa et al. (1999a,b) and Pereira et al. (1999) used the AVHRR sensor in central-African savannas to estimate annual averages for different phytogeographical zones of 19-36% (1981-1991), 3-70% (1985-1987 and 1990-1991) and 61% (1996) (P. M. Barbosa and J. M. Pereira, personal communication, 2000). All of these values represent scenarios and assumptions that are still little studied and that contain large uncertainties due to the scales and the spatial resolutions used. The results for annual means determined for the savannas of northeast Roraima are of a magnitude similar to the overall average of the results of the African studies mentioned above.

In Brazil, no on-the-ground studies exist that determine the percentage area burned in open ecosystems. Kauffman et al. (1994) reported an annual estimate of 50% for Central Brazilian savannas, but the calculation source is not indicated. IPCC (1997, p. 4.25) uses the same value as the “default” in spreadsheets for emission calculations for the whole of Tropical America, citing Hao et al. (1990). The preliminary Brazilian national inventory estimates emissions of gases from burning in non-anthropic savannas by using LANDSAT-TM imagery associated with information on “hot pixels” detected by AVHRR (Brazil, MCT, 2002). The MCT study concluded that, of the total area burned in savannas throughout Brazil in 1999, 8.3% was in clean and dirty field (Sg) types, 14.8% was savanna parkland (Sp), 66.4% arborous savanna (Sa) and 10.5% was “cerradões” (Sd). This last type is counted as forest, rather than savanna, in the reports on land-use change in forest ecosystems (see

Brazil, INPE, 2002). This distribution of burned area done by MCT (Brazil, MCT, 2002) uses the studies by Krug et al. (2001), considering the concentration of "hot pixels" in the different ecosystems. However, this method does not address the question of whether the concentration of "hot pixels" is really a function of the area burned, of the size of the ecosystem or of the persistence of the hot pixels (their persistence will be longer or shorter depending on the vegetation structure and the amount of biomass present). Recently, Krug et al. (2004) drew inferences about the area burned and the recurrence of fires in two LANDSAT scenes in the cerrado of central Brazil using images from LANDSAT-5 TM and LANDSAT-7 ETM for the 1996-2000 period. One can calculate from the results of the study the total area burned declined from 13.8-15.5% (1996) to 4.4-7.0% (2000). Although the study has a reasonably complete sequence of scenes (20 scenes out of a possible 50 (40%) for a sampling period of 160 days of draught), there are still time gaps that are sufficient to mask any growth of the vegetation and hide the true spatial extent to the burning.

Our data from Roraima indicate that the mean percentage of area burned in two-month periods is directly related to (1) human presence, (2) spatial heterogeneity of the biomass, and (3) fire behavior in response to climatic conditions in the year of the observation. Lamotte and Bruson (1985 [1990]) cited by Menaut et al. (1991), found that when savanna fires occur at the beginning of the dry season in the Ivory Coast (December or earlier), they consume up to 12% of the total biomass affected. At the peak of the dry season this value rises to 75% (January), subsequently falling to 13% (February onwards) at the end of the burning season. If one makes assumptions regarding affected biomass and burned area, the distribution presented by Menaut et al. (1991) can be compared to the monthly estimate for Roraima, where 90% of the burned area appeared in the peak months of the dry season. This directly influences the total amount of biomass affected by fire.

6.2. Frequency of Burning

The African studies indicate a period of 1-2 years for recurrence of fires in a given area. The same value (1.5 years) is presented by Lacey et al. (1982) for Australian savannas and by Eiten (1972) for central-Brazilian savannas. Coutinho (1990) and Hoffmann (1998) re-estimated the value as 1-3 years for the Brazilian savannas. Our field results (2.5 years) are higher than the above-mentioned estimates (Table 6).

[***Table 6 here***]

The areas with the greatest recurrence of fire in the savannas of Roraima were concentrated close to the headquarters of the cattle ranches and to indigenous villages that the transect intersected. Multiple burns were associated with the presence of humans. Fires that spread from (or occurred near) human settlements had shorter recurrence periods. This result would be expected because fires are typically anthropogenic. Burning in other areas along the transect, supposedly without human interference, would result from fires started by humans located in any part of the local savannas.

An important finding of our study is it that most (70-80%) of the areas burned in one year do not burn in the following year. In other words, there is always a high percentage of new area being burned in the following period. Similar to our finding in Roraima, the studies by Krug et al. (2004) in central Brazil and by Barbosa et al. (1999a) in central-African savannas found that, respectively, only 16-18% and 9% of the areas burn regularly over time; the remainder of the burning is in new areas. This result implies that the dynamics of fire in these areas lead to a variety of scenarios for the amount of biomass and carbon exposed to burning over time and in different areas. The amount of biomass present is not a fixed value from one year to the next. The rates of biomass increment and carbon should be a function of the dynamics of entrance and exit of material from the ecosystem due to the recurrence of the fires.

With regard to the number of fires occurring in a single year, our study found that, of the total of area burned in a single year, almost all (± 99%) burns only one time. The complete recovery of the low vegetation, which is the principal fuel, is slow and takes at least 4-5 months in years considered to be humid and 6-7 months in years defined as normal. Before this interval of time elapses there is a reduced chance of accumulation of enough biomass to sustain a fire with high intensity and lingering duration. Cases of double burning in a single year are rare (± 1%) and, in general, are observed in places that burned at the end of the dry season of one year, followed by a reburning at the end of the rainy season in the same year.

6.3. Burned area × precipitation (regression model)

Figures 3 and 4 indicate that the burning patterns observed in 1997/1998, 1998/1999 and 1999/2000 are explained as a function of rainfall. These results reinforce the importance of the distribution of the measures of burned area not only for ecosystems, but also for the different climatic conditions at each study site, when applied in calculations of emission of gases from savanna burning.

6.4. Sampling errors

In general, one might infer that the frequency of fires and the percentage of burned area determined by the method used in the present study could be biased as a measure for the area as a whole due to the proximity of highways to all of the fires observed. This inference could come from the fact that the highways are the starting points of development projects and ranches, which would change the density of the vegetation along the highway and make it unrepresentative of the vegetation in the rest of the savanna. However, the highway acts in the same way as any random transect and would count both fires that started from the area of influence of the highways and those that did not. We considered that, under this sampling alternative, fires are virtually always started by humans (both indigenous and non-indigenous), but that, once started, the spreading of the fire is independent of human presence. Therefore, although the sampling error can be considered high, the mean probably would tend to fall very close to the means that would be obtained by randomized or systematic surveys. To test this, we made two overflights (80 and 45 linear km) in April and May 1998 to identify and correct for the error in the estimate of the value of terrestrial area in Sg and Sp for the 1997/1998 biennium. The results of the overflights indicated that the terrestrial transect was able to detect 65-70% of the burned areas (Barbosa, 2001). This result is approximately equal to the 70% value estimated by Barbosa et al. (1999) for central African savannas using remote sensing techniques.

7. Conclusions

(1) values for burned area and fire frequency in the savannas of Roraima are dependent of the vegetation types (structures) and the elevational position (the lower the density of trees and the greater the amount of grassy vegetation in high-altitude areas, the greater will be the percentage of burned area);

(2) the amount of burned area is directly related to the climatic type of the year (dry, wet or normal), which can be inferred from precipitation parameters using simple regression models;

(3) on average, 38 ± 12% of the area of all of the savannas present in Roraima burns annually – a value composed of areas that burn only once in the year (± 99%) and those that burn more than once (± 1%);

(4) the average frequency of burns for the savannas of Roraima is 2.5 years;

(5) most (70-80%) of the area burned in one year does not burn the following year, implying time differences in the approach to calculating biomass dynamics and in models that calculate the emission of greenhouse gases from savannas;

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FIGURE LEGENDS

Figure 1–South America with the location of Roraima and of the savanna area.

Figure 2–Cumulative percentage area burned for “original” savanna ecosystems in Roraima in years of different climatic types.

Figure 3--Daily precipitation and area burned in two-month periods for Sg savannas (clean field + dirty field) in Roraima.

Figure 4—Observed versus calculated area burned.

Table 1 - Caracterization of the ecosystems studied.

Macro System (1)	Ecosystem	Structural type	Crown Cover (%)	Tree stratum (Height)	Estimated Area (2) (km^2)	Transect length (km)
Savanna						
Sg	grassy-woody	clean field	0	Absent	7929	177.8
Sg	grassy-woody	dirty field	< 5	Minimal	5759	129.1
Sp	parkland	parkland cerrado	5-20	2-4 m	11350	133.2
Sa	arboreous	typical cerrado	20-50	3-6 m	547	12.5
Anthropic S	-	(3)	-	-	-	20.5
Others S	-	(4)	-	-	-	31.9
Steppe-like savanna						
Tg	grassy-woody	clean field	0	Absent	198	1.5
Tg	grassy-woody	dirty field	< 5	Minimal	343	2.5
Tp	parkland	parkland cerrado	5-20	2-4 m	5730	19.7
Ta	arboreous	typical cerrado	20-50	3-6 m	666	10.1
Anthropic T	-	(3)	-	-	-	0.5
Others T	-	(4)	-	-	-	0.9

(1) savanna = vegetation situated mainly at altitudes below 600 m, occupying a mosaic of Ultisol and Oxisol soils; Steppe-like savanna = vegetation situated mainly at altitudes above 600 m in a mosaic of litholic soils, including milky quartz.

(2) estimate based on phytoplanimetric maps (1:250,000) in Brazil, Projeto RADAMBRASIL, 1975.

(3) original vegetation modified by human activity without a reliable estimate of area.

(4) other original vegetation that does not fit in the general definition of savannas; included in this category are terrestrial ecosystems such as forest islands and gallery forests and aquatic ecosystems such as rivers and lakes.

Table 2 - Percentage of area burned in the different savanna ecosystems in Roraima from 1997 to 2000.

Ecosystem	Biennium (1) 1997/1998	Biennium (1) 1998/1999	Biennium (1) 1999/2000	Weighted (2) mean	Standard deviation
Sg (clean field)	45.6	28.2	35.6	36	9
Sg (dirty field)	44.9	31.2	36.4	37	7
Sp (parkland)	46.1	26.1	31.8	33	10
Sa (arboreous)	51.0	23.2	21.6	27	17
Sub-Total S	47	28	35	35	9
Tg (clean field)	75.9	84.5	87.9	85	6
Tg (dirty field)	77.3	51.9	53.4	57	14
Tp (parkland)	65.2	29.3	34.9	39	19
Ta (arboreous)	71.6	26.2	29.2	36	25
Sub-Total T	74	35	41	46	21
Overall mean	53	30	36	38	12

(1) A "Biennium" extends from 1 June in one year to 31 May in the next year.

(2) Weighted by the frequency of years that are dry (18.2%), wet (21.2%) and normal (60.6%) for the 1966-1999 period at the Estação Meteorológica de Boa Vista, Roraima (respectively for the biennia 1997/1998, 1998/1999, and 1999/2000).

Table 3 - Area (%) burned in two-month periods and distribution of the concentration of burning in the savannas of Roraima.

Two-month period	Biennium 1997/1998	Biennium 1998/1999	Biennium 1999/2000	Cumulative mean	Concentration of Burned area
June/July	0.0	0.0	0.0	0.0	0.0
August/September	8.4	1.2	1.5	2.7	7.1
October/November	30.3	7.5	7.1	11.4	23.3
December/January	45.2	17.7	23.3	26.1	39.1
February/March	50.5	28.9	35.5	36.8	28.6
April/May	52.5	29.8	35.8	37.6	2.1

Table 4 - Mean frequecy of burning in savanna ecosystems in Roraima (June-July 1997 to April-May 2000).

Biennium	Frequency of burning (n)	Ecosystem (% of area) Sg CL	Sg CS	Sp	Sa	Tg CL	Tg CS	Tp	Ta	Overall annual mean (%)	Distribution of burns (%)	Years needed for repetition of the event
1997-1998	0	31.3	31.7	36.7	49.0	24.1	22.7	34.8	28.4	31.3	-	-
	1	68.6	67.9	63.0	50.7	75.9	76.8	65.0	71.6	68.4	99.6	-
	2	0.1	0.4	0.3	0.3	0.0	0.5	0.2	0.0	0.3	0.4	-
1998/1999	0	71.8	68.8	73.9	76.8	15.5	48.1	70.7	73.8	70.2	-	-
	1	27.9	30.6	25.6	23.0	84.5	51.5	29.2	26.2	29.7	99.6	-
	2	0.3	0.6	0.5	0.2	0.0	0.3	0.1	0.0	0.1	0.4	-
1999/2000	0	64.4	63.6	68.2	78.4	12.1	46.6	65.1	70.8	64.2	-	-
	1	35.3	35.7	31.3	21.4	75.7	51.6	34.1	29.0	35.3	98.4	-
	2	0.3	0.7	0.6	0.2	12.3	1.8	0.8	0.2	0.6	1.6	-
Overall mean	0	60.0	58.9	63.7	72.7	15.0	42.6	60.8	63.8	59.5	-	-
	1	22.5	22.4	21.2	18.3	10.6	16.3	19.8	20.6	22.7	56.0	1.8
	2	14.2	14.3	11.8	7.1	24.3	26.8	14.2	12.4	13.9	34.3	2.9
	3	3.2	4.1	3.1	1.8	37.9	12.5	4.7	3.0	3.7	9.1	11.0
	4	0.1	0.3	0.2	0.1	12.1	1.7	0.6	0.2	0.3	0.6	158.7

(1) Frequency = mean weighted for the 3 years of observation.
(2) Distribution of the burnas refledctws the concentration (in %) of the area burned a a function of the frequency of burning.
(3) Repetition of the event = number of years needed to repeat the burning event at eacy frequency (1, 2, 3 or 4)
observed in three consecutive years in a given area.

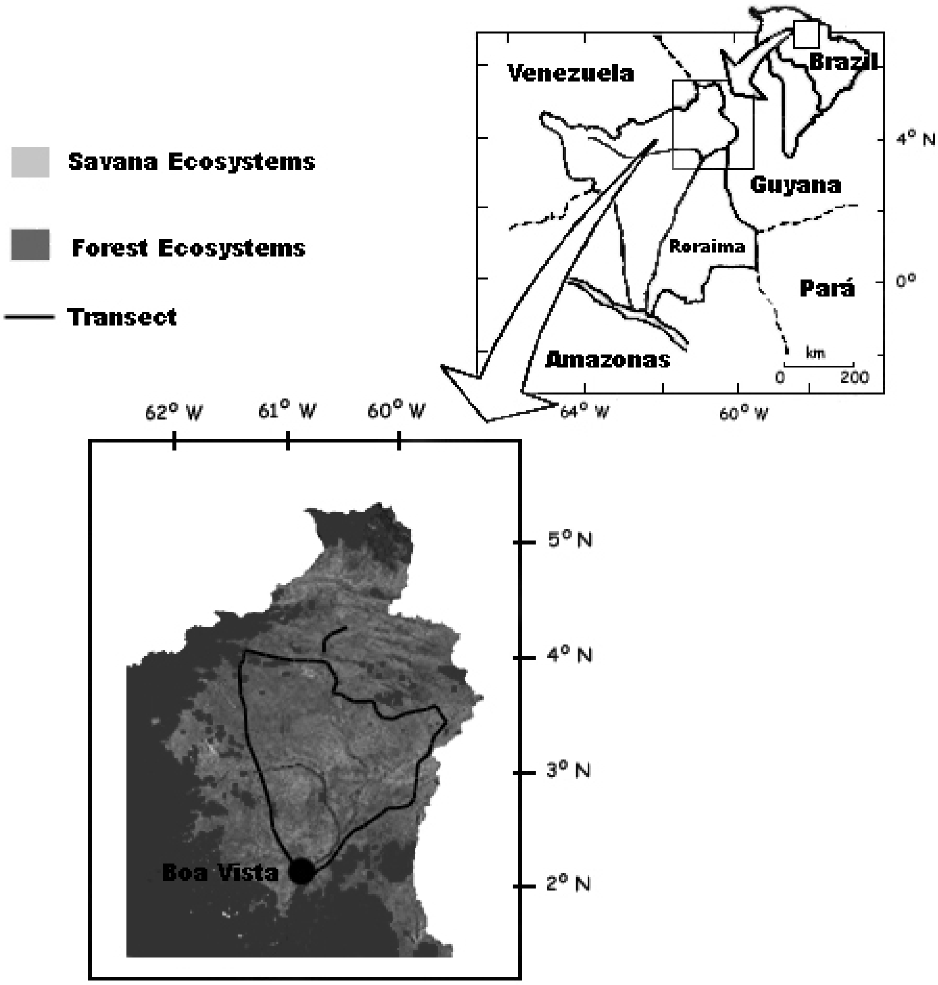
Table 5 - Frequency of coincidence of burning between sequential biennia.

Ecosystem	Frequency of Coincidence	1997/1998 with 1998/1999 (%)	1998/1999 with 1999/2000 (%)
Sg-CL	new areas burned	83.3	32.3
	1 burn in the period	16.5	67.2
	2 or more burns	0.2	0.5
Sg-CS	new areas burned	81.9	85.7
	1 burn in the period	17.5	14.1
	2 or more burns	0.6	0.2
Sp	new areas burned	84.4	88.5
	1 burn in the period	15.1	11.4
	2 or more burns	0.5	0.1
Sa	new areas burned	87.7	95.2
	1 burn in the period	12.3	4.8
	2 or more burns	0.1	0.0
Tg-CL	new areas burned	38.9	71.1
	1 burn in the period	50.0	26.7
	2 or more burns	11.1	2.2
Tg-CS	new areas burned	62.2	85.5
	1 burn in the period	35.1	14.1
	2 or more burns	2.7	0.5
Tp	new areas burned	60.4	80.6
	1 burn in the period	31.4	15.7
	2 or more burns	8.2	3.7
Ta	new areas burned	76.2	89.9
	1 burn in the period	23.5	10.1
	2 or more burns	0.3	0.0
Mean	new areas burned	81.7	71.7
	1 burn in the period	17.4	27.9
	2 or more burns	0.8	0.4

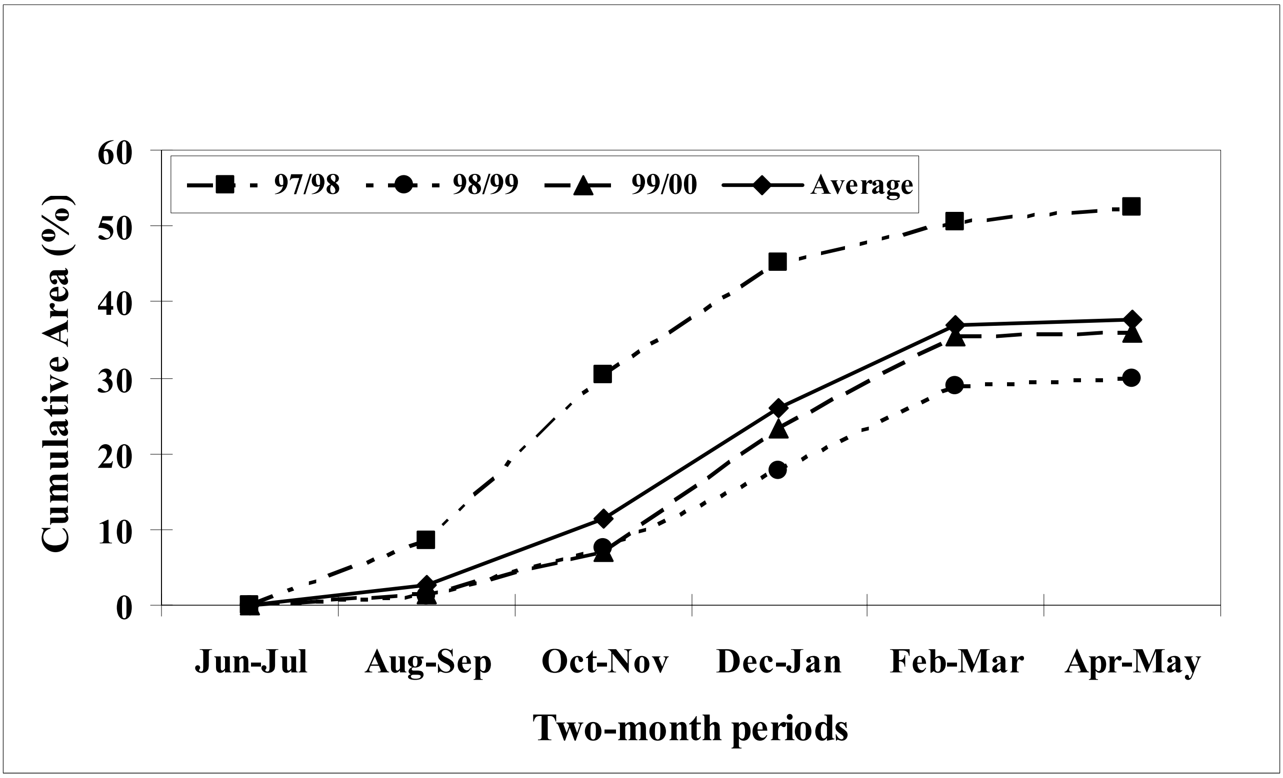
Table 6 - Burning frequencies in savannas

Vegetation type	Location	Frequency of burning (years)	Source	Derivation
EMISSIONS ESTIMATES				
All savannas	worldwide	2.5	Seiler and Crutzen, 1980, p. 226	Deschler, 1974; Fearnside, 1978
All savannas	worldwide	2.5± 1.5	Crutzen and Andreae, 1990, p. 1670	Menaut, 1991
Cerrado	Brazil (central)	1.5 ± 1.5	Hao et al., 1990	Eiten, 1972; Sarmiento and Monasterio, 1977
African savannas	Africa	1.33	Hao et al., 1990	Menaut and Cesar, 1982; Menaut, 1983; J.C.Menaut, personal communication to Hao et al., 1990.
SITE STUDIES				
Cerrado	Brazil (central)	2	Eiten, 1972	

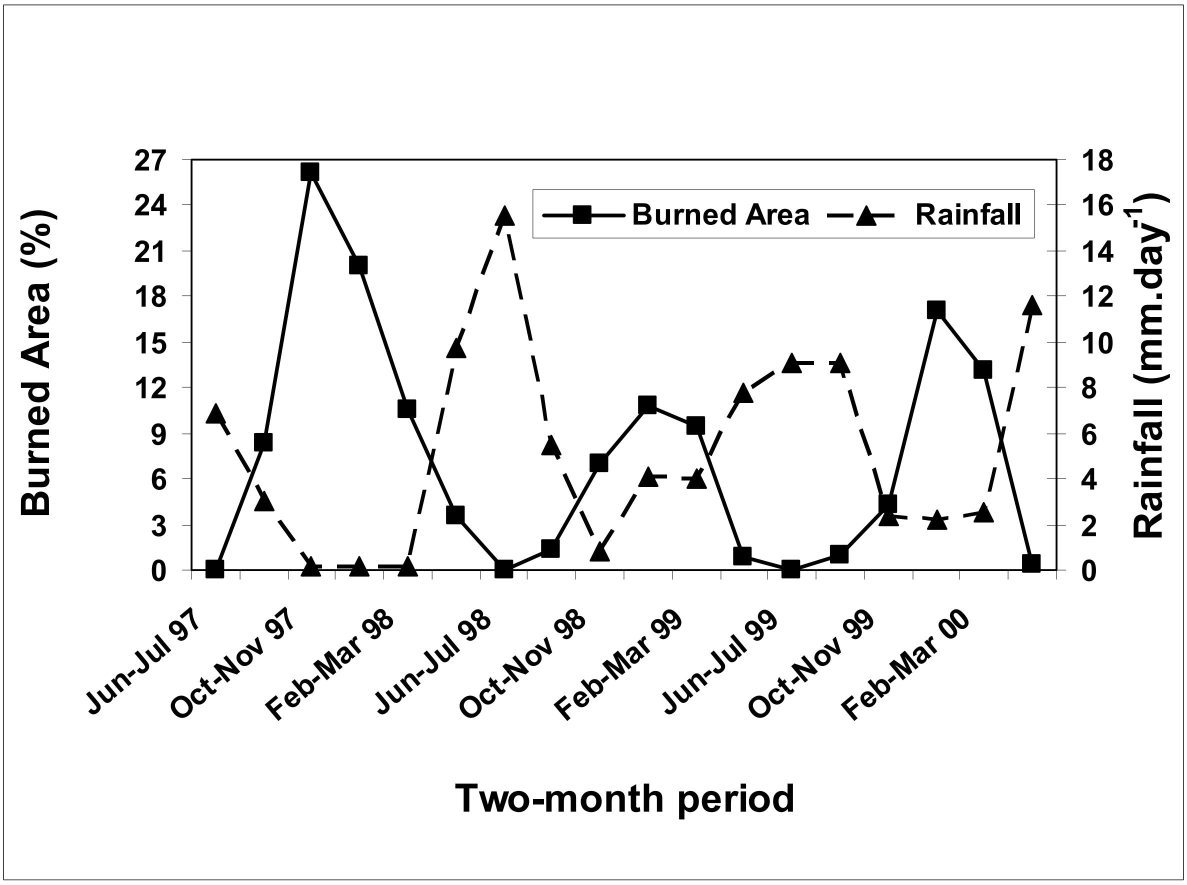
Cerrado	Brazil (central)	1-3	Coutinho, 1990, pp. 87-88
Cerrado	Brazil (central)	3	Pivello and Coutinho, 1992
Roraima savanna (lavrado)	Brazil (northern)	2.5	This study

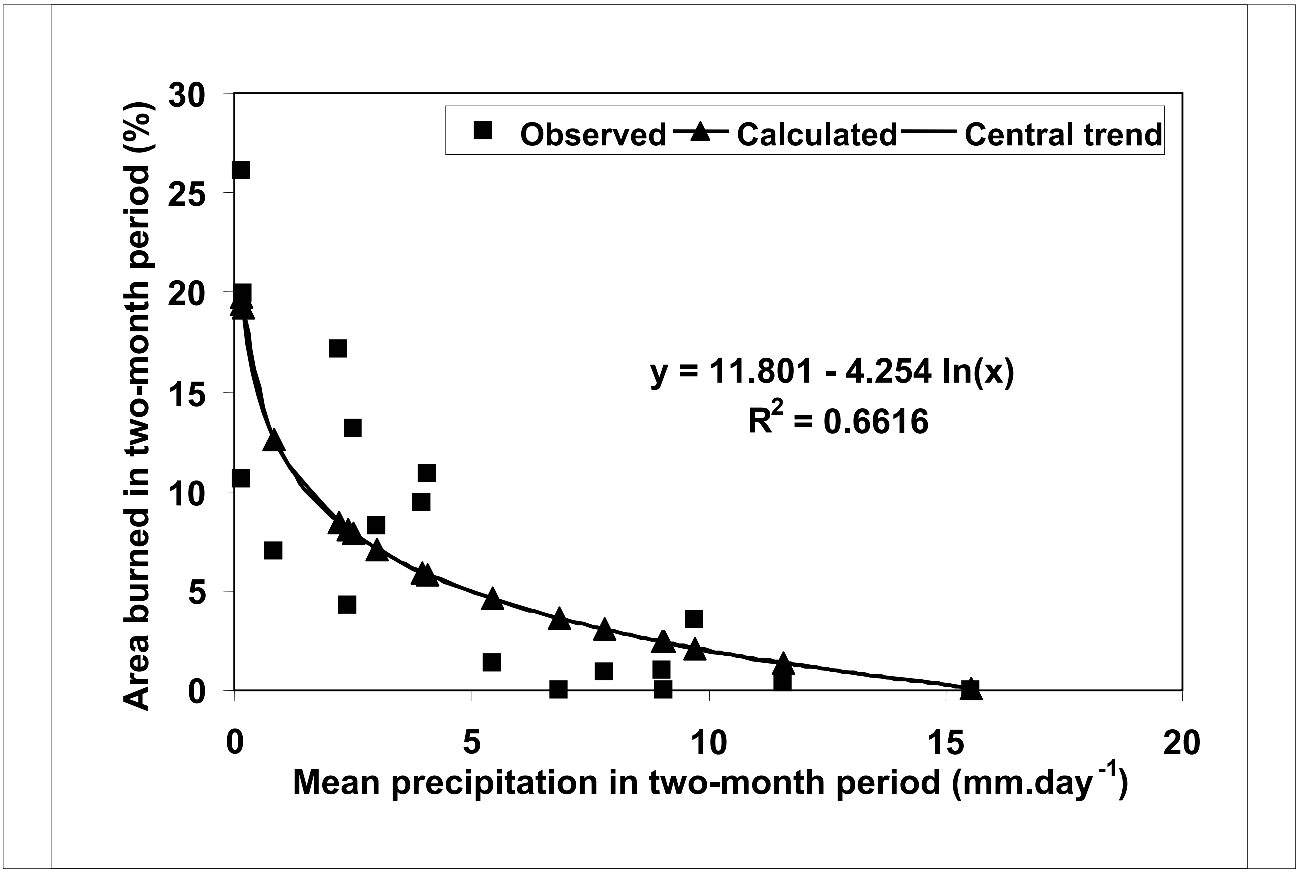


Savana Ecosystems
Forest Ecosystems
Transect
Venezuela
Brazil
Guyana
Roraima
Pará
Amazonas
4° N
0°
km
0 200
64° W
60° W
62° W
61° W
60° W
5° N
4° N
3° N
2° N
Boa Vista



97/98
98/99
99/00
Average
Cumulative Area (%)
60
50
40
30
20
10
0
Jun-Jul
Aug-Sep
Oct-Nov
Dec-Jan
Feb-Mar
Apr-May
Two-month periods


Burned Area
Rainfall
Burned Area (%)
Rainfall (mm.day-1)
27
24
21
18
15
12
9
6
3
0
18
16
14
12
10
8
6
4
2
0
Jun-Jul 97
Oct-Nov 97
Feb-Mar 98
Jun-Jul 98
Oct-Nov 98
Feb-Mar 99
Jun-Jul 99
Oct-Nov 99
Feb-Mar 00
Two-month period


Observed
Calculated
Central trend
y = 11.801 - 4.254 ln(x)
R2 = 0.6616
Area burned in two-month period (%)
Mean precipitation in two-month period (mm.day-1)
0
5
10
15
20
25
30
0
5
10
15
20