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Forest Fires in Roraima, Brazilian Amazonia

Introduction

Forest fires in Amazonia are becoming more evident and frequent in the last years (Nelson 2001, Cochrane 2003). Generally, they cause severe impact in the ecosystem, by increasing tree mortality, causing biomass decrease and modifying original forest structure (Kauffman 1991, Barbosa and Fearnside 1999, Nascimento et al. 2000, Barlow et al. 2003). Negative effects on large groups of animals such as birds (Barlow et al. 2002), mammals (Silveira et al. 1999, J. Fragoso, pers. com.) and reptiles (S. P. Nascimento, pers. com.) are also produced on a large scale due to the reduction of both availability of resources and habitats. Natural resources, such as biodiversity, soil and water are degraded and carbon is released into the atmosphere. Although other examples exist in the Amazon region, the most notable was the "Great Fire" that occurred in Roraima in 1998 (Nepstad et al. 1999a).

Roraima is a 225,116 km^2 Brazilian state located in the northern part of Amazonia and has international borders with the Republic of Guyana and Venezuela (Figure 1). Its variety of reliefs (40 – 2,800m a.s.l.) and landscapes makes it highly rich in biodiversity. Considering terrestrial landscapes in their original form, there are 13 different forest ecosystems (dense, open, contact, etc.) and 9 non-forest ecosystems (savannas, swamps, relics, etc.) in Roraima. In 1998 the El Niño phenomenon resulted in a severe drought in Roraima. Hundreds of burnings (land-use fires) escaped control and turned into several wildfire fronts affecting about 12,000 km^2 of primary forest in the whole state (Barbosa and Fearnside 1999, Shimabukuro et al. 2000, Elvidge et al. 2001).

The area impacted by fire in 1998 represented 6% to 7% of Roraima's original forest ecosystems and more than double of its deforested area up to that year (5,791 km^2). In 1998 the total length of the main fire front lines was about 400 km; the lines were concentrated in the central-western region of Roraima between the middle courses of the Mucajaí and Uraricoera rivers, near the border of Yanomami Indian Land.

Monitoring System

A monitoring and control planning for burning and forest fires was established in Roraima between 1998 and 1999. This strategy intended to improve knowledge of migratory movements taking place into agricultural colonization areas and deforestation due to shifting cultivation. Both activities increase during the dry season (January-March), when fires enter in both forest and savanna ecosystems. The strategy was based mainly on the location and quantification of High-Temperature Events (HTEs or hot spots) from the NOAA-AVHRR satellite sensor (website addresses of INPE with satellite-derived fire maps: see list of references), field inspections and a national alert system that is issued daily for different vegetation types in the whole of Brazil, with emphasis on forest ecosystems and conservation areas like Biological Reserves and National Parks.

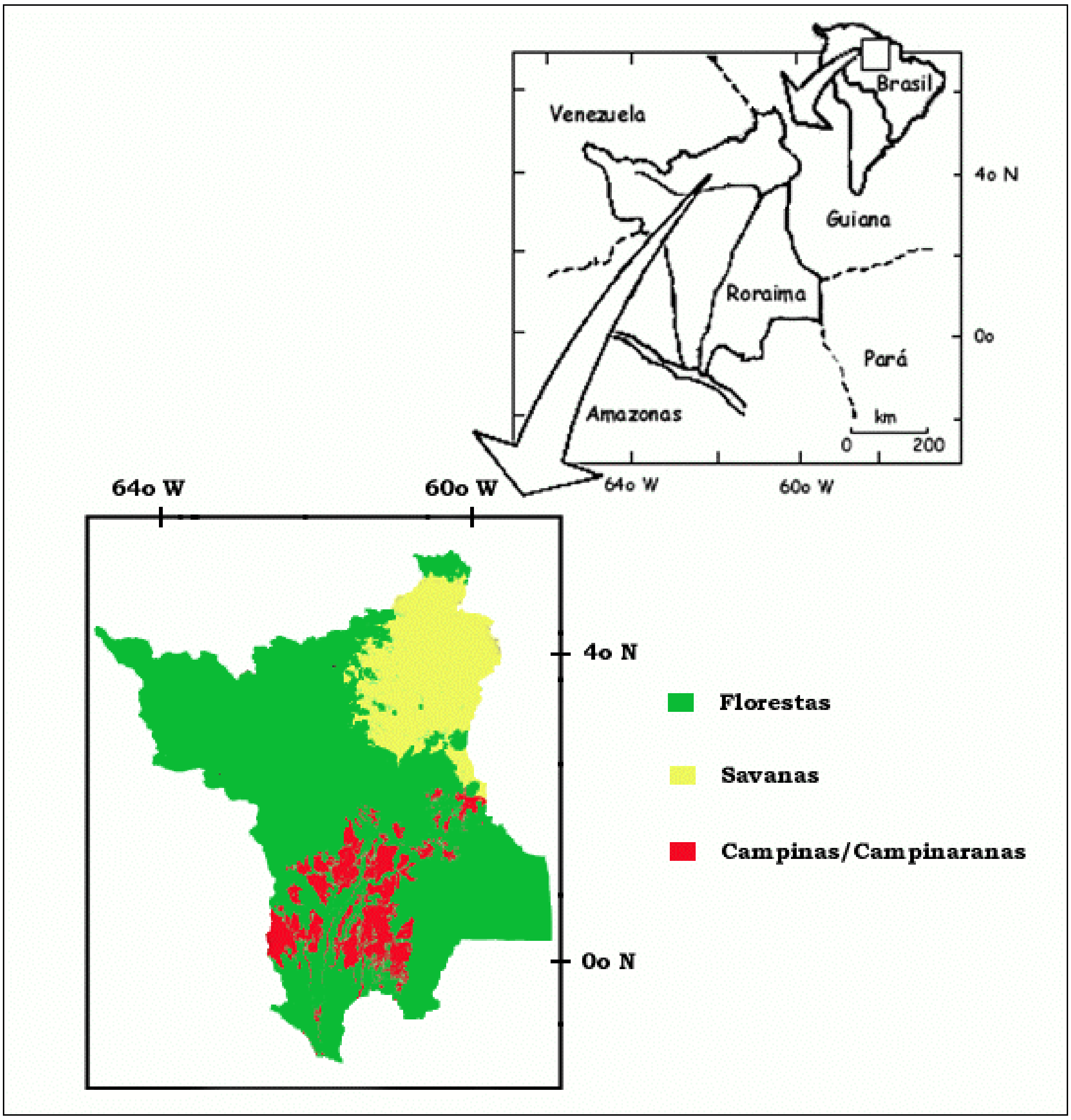

Figure 1. Roraima and its main original vegetation types.

Not all HTEs detected from space indicate the existence of fire (sun glint and heated soil surfaces may also produce a "hot" signal). However, the majority of HTEs depicted actively burning fires. Thus, the amount and concentration of HTEs give a reasonable estimate of the spatio-temporal distribution of fire activities in regions and allow guided strategic actions for prevention and combat to fires. In Roraima, the average of depicted HTEs for 1999 (January) to 2003 (April) was 1,979 per year (Figure 2). Its distribution was 63-81% for forest ecosystems and 19-37% for non forest. The months of larger spots concentration were February (25.8%) and March (46.2%), mainly determined in forest contact ecosystems, environment with the largest records of HTEs (41.3%). This ecosystem is found in the central-western part of Roraima and it has one of the largest network colonization roads in the state. Not coincidentally, this area was almost totally burned by fires out of control in 1998 and 2003.

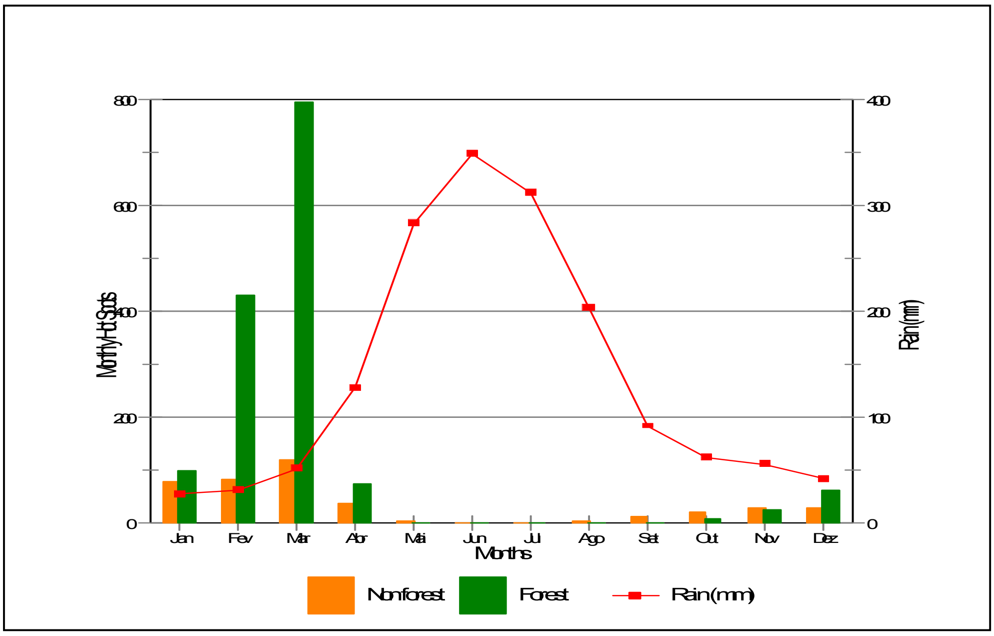

Figure 2. Monthly High-Temperature Events (HTEs or hot spots) detected in Roraima between January 1999 and April 2003.

Following the analysis of fire activities detected from space and on the ground, the control system can be activated and firefighters (fire brigades, Civil Defense, IBAMA) are dispatched to action fires that are out of control (Figure 3). In 2001, a relatively dry year compared to long-term local patterns, this system had to be activated. In early 2003, however, the fire control capabilities were totally exhausted when the El Niño drought, associated with the expansion of colonization fronts into remote primary forest areas of Roraima, created favourable conditions for burnings and uncontrolled wildfires.

Figure 3. Combat of fires in Roraima.

The Great Fire of 2003

Still in the middle of 2002 both the National Institute of Space Research (INPE) and the National Institute of Meteorology (INMET) forecasted that the 2002/2003 biennium would be an "El Niño" period and, a foreseeable consequence would be an accentuated dry phase in the northernmost part of Brazil (website addresses of INPE and INMET: see list of references). At the beginning of 2003 the drought worsened in Roraima, with daily averages of less than 60% relative humidity and air temperatures higher than 35°C. The prolongation of these climate conditions caused water stress in the forest system resulting in shedding of leaves and fine fuels (twigs and small-sized branches) in larger amounts than normal as a form of physiological defence. The accumulation of these dead fine fuels on the forest floor represents an unusual fire hazard (Kauffman et al. 1988). The moisture of these fuels decrease rapidly with low air humidity and high temperatures, and favourable conditions are generated for ignition and propagation of surface fires in forest ecosystems (Uhl et al. 1988). Surface fires consume the accumulated litter layer and facilitate ignition of larger fuels, such as logs and dead branches, especially in gaps (Figure 4).

Figure 4. Front of a surface fire in a forest ecosystem.

Field observations of moisture content (MC) dynamics of fine fuels deposited in different forest environments of Roraima between January 1999 and April 2003 suggest three different categories observed in the dry season (January-March):

- MC 12-18%: areas of primary forest with original structure (without recent influence by fires)
- MC 8-12%: areas affected by fire at least once since 1998, e.g. logging areas, mountains sites or opening exposed to largest sunshine incidence due to gaps, and
- MC < 8%: near the fire front (few meters from the fire), independent of forest structure conditions.

Although with some variation, most of these data were recorded in 15-30 day intervals and at main burning times (11:00-15:00h). Relative air humidity under these conditions and during the El Niño events (like 1998 and 2003) varied between 35-45% in primary forests. Temperatures averaged 34-39°C. These values differ from the historical patterns verified between January-March at the Meteorological Station of Boa Vista: 66-70% relative air humidity and 32-33°C (average of maximum temperatures). These numbers represent a water crisis to natural ecosystems, and suggest strong caution in periods of agricultural burning.

The values of fine fuel moisture of categories (1) and (2) are similar to results obtained by Uhl et al. (1988), at 13:00-14:00h, in the dry season, in both "open" communities (e.g. gaps and *campinas*) - 10%, and "closed" communities (e.g. forests and *campinaranas*) - 18%, in San Carlos of Rio Negro, Venezuela, near Roraima. Although the first case (12-18% in primary forest) can indicate a calm atmosphere, this is not true when heat irradiation of burning material from anthropogenic ecosystems (pastures, secondary forests and logging areas) creates appropriate conditions for fire penetration into those forests that had just been burned in 1998 and were under strong water deficit. Even forests without recent records of fire, which in theory would be under natural protection (Holdsworth and Uhl 1997, Nelson and Irmão 1998, Nepstad et al. 1999b), become fire-vulnerable due to heat transfer between adjacent ecosystems, causing the fuel moisture to drop quickly and facilitating combustion.

Considering the coupled or accumulating effects of conditions favourable for the start and spread wildfires, such as the drought prolonged by El Niño, burning activities, anthropogenic alterations in the affected systems, water deficit and large volumes of fuel, it was not difficult to forecast fire events in 2003 similar to 1998. These events were observed in regions where the human component is already established and where composition and structure of forest areas had already been affected by the 1998 fires. Forests with recent fire records show apparent positive feedback because they provide conditions favourable to support the spread of new fires in the succeeding years (Cochrane et al. 1999, Siegert et al. 2001).

In the first days of February 2003 fire already appeared in several mountains on areas with large concentrations of dry fuel. At the beginning of March there were already three established fire lines in the western and central-western regions of Roraima. The largest one was located near Apiaú, Campos Novos and Roxinho, areas strongly affected in 1998. Based on the speed of surface fire propagation in the forest (0.95 ± 0.46 km per day) and on the length of the fire lines we estimate that about 85 ± 42 km^2 of primary forest were affected daily by fire in that period. Based on greenhouse gas emissions estimates for the 1998 wildfires in primary forest (Barbosa and Fearnside 1999), about 3.5-4.0 tons of carbon were released as CO_2 for each hectare burned.

Despite field teams attempts to put out the fires the fire activities slowed down only between 20 and 21 March 2003 when the first rains fell at the beginning of the Northern Hemisphere spring. Until the first days of April there were fire spots between the middle course of Mucajaí river and the Serra do Repartimento region. Estimates based on aerial surveillance indicate that in this area alone about 2,000-2,500 km^2 of forests were burned in 2003. The fires severity affected the ecosystem structure and increased the susceptibility for future fires of larger intensity. Even with great uncertainties due to impacts generated in several regions and lack of recent satellite images with high-resolution sensors such as LANDSAT TM or SPOT, we believe that the area affected by fire in 2003 in Roraima was a large but not so extensive as the area burned in 1998.

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