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Alterations following a fire in a forest community of Alto Rio Xingu

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Abstract

This study records the consequences of fire upon the soil and structure of the Amazonian Forest of Gaúcha do Norte, Mato Grosso state, Brazil (13°12′S and 53°20′W). For this, the number of individuals sampled in 1 ha of the forest, during a phytosociological survey completed 2 days before the accidental fire, was compared with the survivors recorded afterwards in the reinventory of the area taken 2 days and 10 months after the fire. For the surveys, the area of 1 ha was subdivided into 50 plots of 10 m × 20 m, and all the individuals with circumference at breast height (CBH) $\geq$ 15 cm were sampled. Chemical analysis of the 30 soil samples collected 2 days before the fire were compared with those obtained 15 days and 1 year after the fire. It was seen that, soon after the fire, there was a significant increase in the nutrient levels in the soil, an increase in the pH and a decrease in the aluminum toxicity. However, after 1 year, losses by lixiviation resulted in a nutrient reserve in the soil of less than that before the fire. The tree mortality was extremely high (23.98%), particularly amongst the younger individuals of the population (93.68% of the total of deaths in the period). There was no significant reduction in the forest richness analyzed: 60% of the species had reduced populations after the fire, but just four species were locally extinct. Results, however, demonstrated a role for fire in the selection of resistant species or those adapted to fires, since some species demonstrated a greater tolerance to the fire than others.

Keywords: Amazonia; Tropical evergreen forest; Forest vegetation; Forest soil; Fire effect

1. Introduction

Fire has been influencing the structure and composition of Amazonian forests for thousands of years. In the northeast of the Amazon basin, the presence of charcoal in the soil indicates the occurrence of fire during the last 6000 years, at a time in which the climate was drier and the vegetation was scleromorphic (Uhl and Kauffman, 1990; Holdsworth and Uhl, 1998). Nowadays, the microclimate and the high rainfall create non-inflammable conditions, making fires—in the majority of non-perturbed rain forests with high and closed canopies—virtually impossible (Pires and Koury, 1958; Uhl and Kauffman, 1990).

In contrast with scrub land, the evergreen forest demonstrates few evolutionary adaptations for fire

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survival. The extremely low capacity of the primary forest to survive even low intensity fires suggests that the occurrence of fire is extremely rare in this ecosystem (Kauffman and Uhl, 1990). Thus, frequent fires may cause the extinction of the current vegetation or the conversion of the remaining tropical forest into sclerophilic rain forest (Melick and Ashton, 1991).

The tropical rain forest is being radically transformed as a result of human activity, creating a mosaic of exploited forests, cultured fields and secondary forests (Uhl and Kauffman, 1990). In the substitution or management of forest areas, fire is used as a cultural and traditional agricultural tool by a large variety of ethnic groups (Goldammer, 1988).

The increase in rural occupation has resulted in an alarming rise in fire pressure upon the remaining forests (Goldammer, 1988), accelerating the processes of degradation and transforming non-inflammable tropical forests into inflammable secondary communities. Exploited ecosystems represent a new and unique environment for fire in the Amazon; the combustible mass is high, the modification of the microclimate promotes rapid drying of this combustible mass and anthropogenic ignitions are common (Uhl and Kauffman, 1990).

Undoubtedly, the frequency and wide spread use of fire in the Amazon is dramatically altering the successional patterns, the structure and the composition of the forest (Kauffman and Uhl, 1990). If the use of fire is not controlled, such as rigid control and adequate legislation, the fires will tend to increase in size, becoming more dangerous. This fire regime may irreversibly change the basic characteristics of the Amazon forest (Uhl et al., 1990).

Inside the Amazon forest, half the rain which falls upon the forest is generated by the forest itself. In a paradoxical manner, a large part of the vapor emitted to the atmosphere by the forest comes from the regions which undergo seasonal droughts, principally in the east and south of the Amazon, the forests undergo 3–5 months of severe drought during which the quantity of rain fall is much lower than the quantity of water emitted by the forest into the atmosphere via evapotranspiration (Gash, 1996). This phenomenon is made possible by the fact that the forests have a system of roots capable of absorbing water at depths of more than 10 m during the annual dry seasons (Nepstad et al., 1994; Moutinho and Nepstad, 1999). If these forests were substituted with pasture, the volume of vapor emitted into the atmosphere would be severely reduced, since pastures present an evapotranspiration of 15% below that of the forests (Jipp et al., 1998).

The cool temperature and the high humidity make the majority of non-perturbed rain forests non-inflammable, since they make difficult the drying of combustible mass (litter layer) that does not reach the ignition point (Uhl et al., 1990). Unfortunately, the Amazon forests are losing their capacity to act as great ‘‘fire breakers’’ along the country side (Nepstad et al., 1994), one of the most important ecological services of the forest, making megafire phenomena more and more probable.

Under a drier climate, therefore, the factor which most threatens the biodiversity of the Amazon, in the near future, seems to be fire. This threat may be greater in the eastern region of the Amazon, where the forests suffer seasonal droughts, and at the frontiers of Amazonian occupation, established principally by the use of fire for deforestment (Moutinho and Nepstad, 1999).

Thus, the permanence of the forests of the eastern Amazon represents a guarantee of preservation, not only of the climate and biodiversity, but also of the productive activity and the quality of life of the local populations (Moutinho and Nepstad, 1999). The forests which undergo seasonal drought, which cover a third of the Amazonian area, should therefore be prioritized by conservation plans.

As a recurring perturbation, fire has an unparalleled potential to deplete and alter the forests of the eastern Amazon region (Cochrane and Schulze, 1999). From this point of view, forecasts of the responses of forests to the increase in environmental degradation become more and more relevant. The understanding of how natural communities regenerate following perturbational, anthropical or natural actions and information to determine which species will resist and, maybe more importantly, which organisms will be lost are therefore of absolute necessity (Kauffman, 1991; Castellani and Stubblebine, 1993).

This study presents comparative data of the soil, of the structure and the floristic composition of a stretch of forest in the eastern Amazon region, subject to seasonal drought, before and after it was affected by an accidental fire of low intensity. The objective of this investigation is to analyze the impact of fire upon this community.

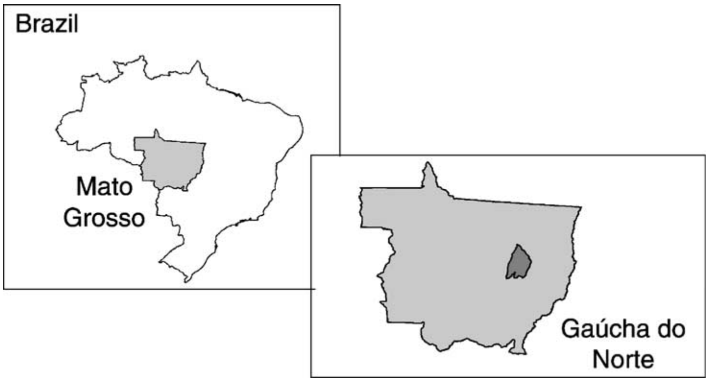

Fig. 1. Location of Gaúcha do Norte, state of Mato Grosso, Brazil.

2. Methods

2.1. Study area

The municipality of Gaúcha do Norte (Fig. 1) occupies an area of 16958.69 km^2 and houses a population of 3277 inhabitants, part of the population being indigenous and the remainder being migrants from the south of the Brazil, the latter arriving by way of businesses colonizing the region during the last 20 years.

The northern region of the municipality is part of an indigenous area of the Xingu Indigenous Park (Parque Indígena do Xingu) and the local forest can be found in a well-preserved state. The southern region, in contrast, demonstrates strong anthropic pressure, with stretches of forest still in a good state of preservation fragmented by the opening of agricultural areas: 4000 ha of soya, 1525 ha of rice and 153 ha of corn (O'Estadão Matogrossense, 1999). There is no available data as to the area occupied by pastures, but the bovine herd is made up of 105,000 animals. Farmers also invest, on a smaller scale, in rubber and cashew plantations. A lumber industry has also surged in the region, with workers generally looking for Timbori (*Trattinikia* spp.).

During recent years the municipality's population has been rapidly increasing due to the arrival of migrants from other regions of the Mato Grosso state and even the south of the country. This migrant flow has occurred largely as a result of the construction of highways and bridges which has facilitated the communication and passage of people between the region and the neighboring municipalities of Paranatinga (with access via the MT-020) and Canarana and Nova Ubiratã (via the BR-242).

With the growth of the municipality and the building of highways, the cutting and burning of forests has increased at an alarming rate. In turn, fires have become more frequent and, during the dry period of 1999, extensive areas of forest were burnt.

The regional climate is Aw type by the Köeppen classification (Ometto, 1981). The mean annual temperature is 26 °C and the average annual rainfall is 1508 mm; there is a dry season from May to October.

The study was carried out on a stretch of evergreen seasonal forest which lies on oxisol on the private property of Lauri Stoffel (13°12′S and 53°20′W). This forest suffered the impact of what is commonly known as "creeping fire", a fire of low intensity, during the megafire which occurred in the region in October 1999.

2.2. Soil analysis

One hectare of forest was sub-divided into 100 neighboring plots of 10 m × 10 m, of which 10 plots were chosen for the collection of soil samples at three depths: 5–20, 20–40 and 60–80 cm. Samples were collected on three dates: 6/10/1999 (period before the fire), 21/10/1999 (12 days after the fire) and 15/10/2000 (approximately 1 year after the fire).

Each sample was collected with the aid of a Dutch auger, and was stored in a 0.5 l plastic bag before labeling and transporting to the laboratory of Soil Sciences, ESALQ/USP, Brazil.

The means of the soil chemical attributes at each depth were compared by a analysis of variance (ANOVA) and those parameters which demonstrated differences at a 5% level of significance were submitted to the Tukey test to show which means should be considered as statistically different (Costa Neto, 1977). For both the analyses the inerSTAT-1 (Vargas, 1999) program was used.

2.3. Phytosociological survey

A phytosociological survey was performed in July–September 1999, in a 1 ha square of forest which was subdivided into 50 plots of 10 m × 20 m. All individuals in these plots with circumference at breast height (CBH) $\geq$ 15 cm were sampled, with the exception of those individuals which stood above the soil, but below breast height (1.30 m). For this, the following criterion was adopted: the individual was included when at least one of the branches obeyed the inclusion criterion (CBH $\geq$ 15 cm), the CBHs of the all branches were then recorded for the calculation of the basal area. For each individual sampled, CBH, height (distance of the apex of the crown from the soil in a perpendicular line) and field observations were recorded and botanical material was collected for identification.

The identification of botanical material was undertaken using analytical keys, specialized bibliographies, comparisons with material previously identified by specialists, and direct consultations with these specialists whenever necessary. The plants classification system of Cronquist (1988) was adopted. Botanical specimens are deposited in the herbarium of the Escola Superior de Agricultura "Luiz de Queiroz" of the São Paulo State University (ESA), State University of Mato Grosso (NX) and State University of Campinas (UEC).

The phytosociological parameters, those described by Whittaker (1972) and Mueller-Dombois and Ellemberg (1974), were obtained using the FITOPAC program (Shepherd, 1994).

At the beginning of October 1999 (9/10), the forest was affected by a fire which started in an area of pasture, some kilometers away from the research area, and extended to all the interfluvial. Inside the forest the fire was low lying, locally called "creeping fire", and did not reach the string which marked out the plots. The flames only reached great heights in localized areas, principally in the clearings where there were already dead trees.

In December 1999, a reinventory was taken of the area sampled during the phytosociological survey, counting the individuals which had died and the survivors of the fire. Mortality was defined as the individuals with no vegetative activity or those which had disappeared (Oliveira, 1997). A new inventory was performed in August 2000, to verify whether the mortality rate of the individuals continued to increase even 10 months after the fire.

3. Results and discussion

3.1. Soils

The mean values of the parameters of the soils sampled at depths of 5–20, 20–40 and 60–80 cm, before and after the fire are presented in Table 1.

It may be noted that, immediately after the fire (15 days), there was a perceptible increase in the levels of potassium, calcium and magnesium, resulting in an elevation in the pH and a lower aluminum saturation (*m*, %). The quantity of organic material was not altered and there was a small decrease in phosphorus at depth. Elevation in pH, decrease in aluminum concentration and, contrary to our study, an increase in phosphorus levels in post-fire forest soils have previously been reported in the Amazon region (Fearnside, 1990).

However, 1 year after the fire, the levels of potassium, calcium and magnesium returned to these values obtained before the fire with a consequent decrease in the base saturation (*V*, %), an increase in the aluminum concentration (*m*, %) and a decrease in the pH (Table 1).

Thus, there was a significant increase in the nutrients in the soil soon after the fire, due to the lixiviation of bases originating from the mineralization of the litter layer. With the elevation of pH, base saturation increases and aluminum toxicity decreases. Unfortunately, these aspects which are favorable for the development of plants did not continue for very long and with the beginning of the rainy season, losses were increased due to lixiviation. During rain, anions may be dragged by the percolation of water (van Raij,

Table 1
Chemical analysis of oxisol before and after the fire in an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil[a]

Date	Depth (cm)					
	5–20		20–40		60–80	
	M	S.D.	*M*	S.D.	*M*	S.D.
pH $CaCl_2$						
BF[b]	3.3	0.1 a	3.6	0.1 a	3.7	0.1 a
12 days AF[c]	3.9	0.3 ab	4.0	0.2 ab	4.2	0.1 ab
1 year AF[d]	3.5	0.1 b	3.5	0.2 b	3.8	0.1 b
OM (g/dm^3)						
BF	21	4 a	17	2 a	12	2
12 days AF	20	5 b	17	4 b	11	1 a
1 year AF	27	5 ab	24	4 ab	14	3 a
P (mg/dm^3)						
BF	10	2	7	1	4	0 ab
12 days AF	11	4	9	4	3	1 a
1 year AF	8	11	7	5	3	1 b
K ($mmol_c/dm^3$)						
BF	0.6	0.1 a	0.5	0.1 a	0.3	0.1 a
12 days AF	1.7	0.5 ab	1.8	0.6 ab	2.3	1.7 ab
1 year AF	0.7	0.3 b	0.6	0.2 b	0.3	0.2 b
Ca ($mmol_c/dm^3$)						
BF	1	0 a	1	0 a	1	0 a
12 days AF	8	3 ab	11	6 ab	9	3 ab
1 year AF	1	1 b	1	1 b	1	0 b
Mg ($mmol_c/dm^3$)						
BF	1	0	1	0	1	0
12 days AF	3	1	4	2	4	1
1 year AF	2	1	2	1	1	1
Al ($mmol_c/dm^3$)						
BF	23	5 a	18	3 a	10	2 a
12 days AF	16	7 b	9	3 b	19	9 ab
1 year AF	14	3 c	14	3 c	9	2 b
H + Al ($mmol_c/dm^3$)						
BF	92	18	72	10	48	11
12 days AF	85	25	74	23	40	8
1 year AF	79	28	79	25	40	8
SB ($mmol_c/dm^3$)						
BF	2.7	0.2 a	2.8	0.7 a	2.3	0.1 a
12 days AF	12.7	4.3 ab	16.1	7.8 ab	14.6	4.2 ab
1 year AF	3.9	1.4 b	3.5	1.5 b	2.8	0.7 b
T ($mmol_c/dm^3$)						
BF	94.9	18.3	75.0	9.9	50.2	11.4
12 days AF	97.3	25.7	89.7	28.0	54.5	9.9
1 year AF	83.7	27.4	82.5	25.3	43.3	8.3
V (%)						
BF	3	1 a	4	1 a	5	1 a
12 days AF	14	5 ab	18	6 ab	27	7 ab
1 year AF	5	3 b	4	2 b	6	2 b
m (%)						
BF	89	3 a	86	4 a	80	3 a
12 days AF	55	11 b	37	12 ab	52	21 ab
1 year AF	78	7 c	79	8 b	75	5 b

[a] *M*: mean; S.D.: standard deviation; OM: organic material; SB: sum of bases; *T*: cation exchange capacity; *V*: base saturation; *m*: aluminum saturation. Significant differences between the soils ($P < 0.05$, ANOVA and Tukey test) are indicated by letters.

[b] Before fire (6/10/1999).

[c] After fire (21/10/1999).

[d] After fire (15/10/2000).

1991), taking with them an equivalent quantity of cations, usually, calcium, magnesium and potassium. The basic nutrients are therefore substituted by acidifying elements such as hydrogen and aluminum, which occupy the cation exchange capacity of the soil (Lopes, 1989). At low pH, the availability of bases is decreased.

In tropical forests, the nutrient stock of the soil is maintained via biological nutrient recycling: cations and anions are absorbed by the roots of the plants and then return to the soil via precipitation and by the deposition and mineralization of the litter (Sparovek, 1993). In a burnt forest, the process of mineralization of the litter is rapidly accelerated, supplying a greater quantity of nutrients than the surviving plants are capable of absorbing. In the rainy period, this excess of nutrients is lixiviated, causing losses to the system. This accentuated loss may result in a level of nutrients in the soil equal to or lower than that before the fire if the litter produced after the fire is not produced in a sufficient quantity to maintain the stock necessary for the plants.

3.2. Vegetation

The fire reduces the larger individuals of the forest community, as observed in the shrub-woody populations present in the study area: of the 1122 live samples in 1 ha of forest before the fire, 269 (23.98%) died during the 20 months after the fire

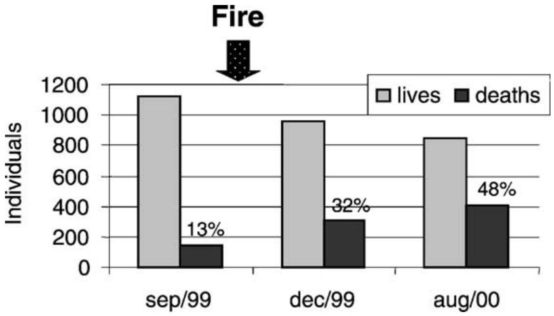

Fig. 2. Tree population in the period before (September 1999) and after (December 1999 and August 2000) a fire in an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil. The numbers on the bars are the percentage of death trees.

(Fig. 2). This tree mortality is extremely high when compared with the rates found in preserved forests in the Amazon region (Oliveira, 1997).

This high tree mortality was expected, since the Amazon forest has few evolutionary adaptations to resist fire, which is naturally a rare event in this formation (Kauffman and Uhl, 1990). The reduction in the density of woody individuals in tropical forests after fires was demonstrated by Cochrane and Schulze (1999). Fire has an even greater destructive power in forests previously submitted to selective extrativism, affecting 44% of the individuals with diameters of greater than 10 cm (Holdsworth and Uhl, 1998).

Not all the trees died immediately after the fire, since the mortality increased with time (Figs. 2 and 3).

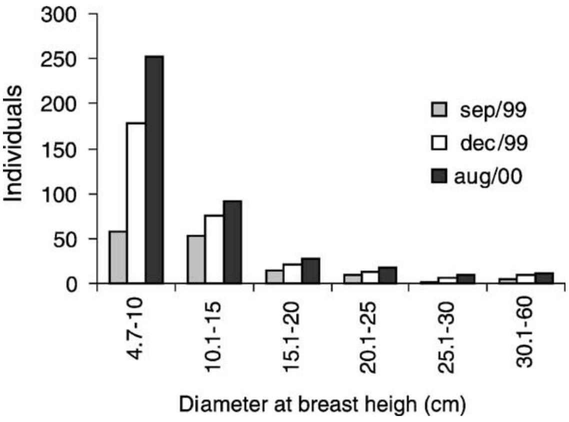

Fig. 3. Total of dead individuals in the period before (September 1999) and after (December 1999 and August 2000) a fire in an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil. The numbers on the bars are the percentage of death trees.

The same phenomenon was observed in Paragominas-PA, with tree mortality of 38% after 1 month and 55% 1 year after a fire (Holdsworth and Uhl, 1998).

The action of low-lying fire upon the forest also resulted in the death of the majority of the individuals present in the undercanopy and understory: a clear contrast was seen between the brown colors of the leaves of these layers up to a variable height of 5–10 m with the green of the trees of the canopy which survived the fire. This occurred because the majority of the trees and saps of the undercanopy and understory did not die as a direct result of the flames at the moment of the fire, but as a result of the dehydration of the crown as a consequence of the elevated temperature associated with the large loss in the volume of their roots.

The greatest impact of the fire upon the lower layers of the forest can be seen in Fig. 3, which presents the total number of dead individuals, distributed according to their diametric class. It can also be seen that the individuals with smaller diameters were affected more severely, representing 93.68% of the total of deaths in the period.

In natural conditions, the mortality rates for different inclusion diameters do not demonstrate a defined pattern. Oliveira (1997) analyzed 3 ha of evergreen forest in the Manaus region and observed that in one of the hectares the mortality rate had a positive correlation with the increase in diameter, but in the other two hectares the correlation was negative. The mortality rate, though, for the individuals below 10 cm in diameter was 0.99 ± 0.31% in 5 years of observation, reaching 0.87 ± 0.62% in the final class of individuals which had diameters of more than 25 cm.

Thus, fire may be considered to have a severe impact on the populational structure of the tropical forests, principally affecting the youngest individuals of these populations. According to Cochrane and Schulze (1999), the individuals with greater diameters may be more able to survive contact with fire than those with smaller diameters, this has also been observed in other tropical forests subject to a single fire (Uhl and Buschbacher, 1985; Woods, 1989; Holdsworth and Uhl, 1998). However, in forests which are frequently burnt or in fires with high flames, the large trees seem to be just as susceptible to fire as those with smaller diameters, resulting in similar mortality rates (Uhl and Buschbacher, 1985; Kauffman, 1991;

Cochrane and Schulze, 1999). In the case of frequently burnt forests, the increase in the mortality of the large trees may be attributed to their weakening (Cochrane and Schulze, 1999).

Temperate forests do not seem to respond in the same manner as tropical forests as regards the diametric class most affected by fire: Kauffman and Martin (1991) found a positive correlation between the post-fire survival and the size of the plant in frequently burnt temperate forests.

Despite the reduction in the number of individuals, there was no significant reduction in the number of species in the forest analyzed: of the total of 75 species present in 1 ha before the fire, the populations of 45 species (60%) were reduced after the fire, but just four species, sampled as single individuals, were locally extinct after the fire (Table 2). However, in forests subject to a more intense fire or more frequent fires, and evaluated for a greater period, it has been observed that the species richness is inversely proportional to the seriousness of the fire (Cochrane and Schulze, 1999).

A critical question for the understanding of the effect of fire upon the forest composition is the possible effect of fire upon the selectivity of species which are resistant or adapted to fire.

In the community level, the individuals with smaller diameters had more mortality than those with greater diameters (Fig. 3). It would be natural to conclude that the species with small size were also more susceptible to fire. However, this hypothesis was not confirmed, since species with similar diameters had different mortality (Fig. 4).

In the forest analyzed, fire was observed not to affect the area in a uniform manner, augmenting its combustion power in border areas and in clearings, due to the hotter and drier microclime resulting from the direct incidence of solar rays (Kauffman and Uhl, 1990; Uhl and Kauffman, 1990; Holdsworth and Uhl, 1998). Species more tolerant to fire than others also seem to exist in extremely unequal densities and spatial patterns. These associated factors result in differentiated mortality among populations, as shown in Table 2.

However, species with approximately the same density and frequency, which occupy similar tiers, present very distinct tree mortality. This fact indicates that those species have different degrees of tolerance to fire, which cannot be considered casual consequence of local variation in burn intensity.

This is the case of *Aparisthmium cordatum*, a species of the intermediate tier and very common in the forest analyzed, which had its population drastically reduced after the fire, in contrast to *Amaioua guianensis* which, whilst also suffering population reduction, did not reach such elevated levels of reduction. This and other examples may be seen in Fig. 5.

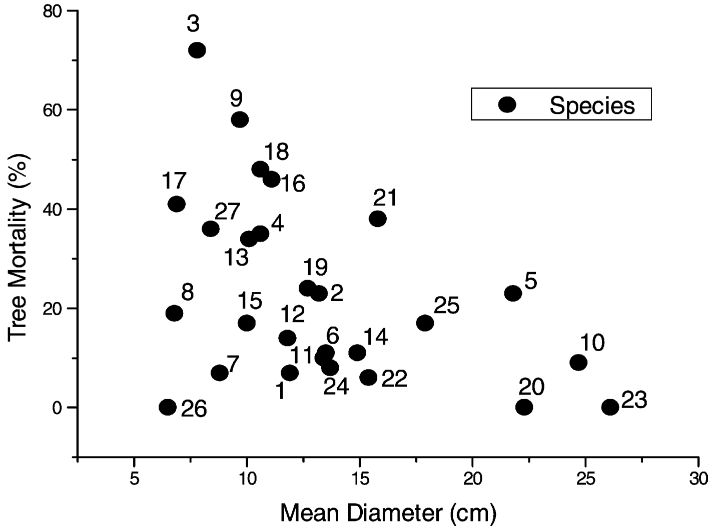

Fig. 4. The relationship between tree mortality and mean diameter of 27 species sampled in 1 ha of an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil (only populations with more than 10 individuals were included). The numbers of species follow the same legend of Table 2.

Table 2
Tree species population before (October 1999) and after a fire (December 1999 and August 2000) in an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil[a]

	Species	Initial population				Survivors		Tree mortality (%)	
		October 1999				December 1999	August 2000	December 1999	August 2000
		NI/ha	DeR	DoR	FR	NI/ha	NI/ha		
1	*A. guianensis* Aubl.	106	9.45	6.68	5.97	102	99	4	7
2	*Miconia* cf. *pyrifolia* Naudin	92	8.20	7.94	5.69	81	71	12	23
3	*A. cordatum* Baill	81	7.22	2.20	2.78	43	23	47	72
4	*Ocotea guianensis* Aubl.	75	6.68	4.58	4.31	60	49	20	35
5	*Nectandra* aff. *Cissiflora* Nees	71	6.33	17.31	5.83	62	61	21	23
6	*Sloanea robusta* Vittien	57	5.08	4.83	5.00	52	51	9	11
7	*Cheiloclinium cognatum* (Miers) A.C.Sm.	44	3.92	1.45	3.61	42	41	5	7
8	*Protium pilosissimum* Engl.	37	3.30	0.73	3.47	33	30	11	19
9	*Miconia cuspidata* Naudin	36	3.21	1.50	4.17	27	15	25	58
10	*Guatteria* cf. *foliosa* Benth.	33	2.94	9.13	3.61	32	30	3	9
11	*Trattinickia glaziovii* Swart.	29	2.58	3.06	3.06	23	19	21	34
12	*Ouratea discophora* Ducke	29	2.58	1.73	2.50	26	25	10	14
13	*Chaetocarpus echinocarpus* (Baill.) Ducke	29	2.58	1.31	3.75	27	26	7	10
14	*Xylopia amazonica* R.E.Fr.	27	2.41	2.51	2.08	26	24	4	11
15	*Miconia* cf. *elaeagnoides* Cogn.	24	2.14	1.01	2.22	20	13	17	46
16	*Guatteria* cf. *schomburgkiana* Mart.	24	2.14	1.31	2.36	21	20	13	17
17	*Guatteriopsis blepharophylla* (Mart.) R.E.Fr.	22	1.96	0.57	2.36	14	13	36	41
18	*J. copaia* (Aubl.) D. Don.	21	1.87	1.20	2.22	13	11	38	48
19	*Ocotea* sp.	21	1.87	1.85	2.78	17	16	19	24
20	*Sacoglottis mattogrossensis* Malme	19	1.69	4.16	1.94	19	19	0	0
21	*Bellucia grossularioides* (L.) Triana	16	1.43	1.78	1.53	15	10	6	38
22	*Pseudolmedia macrophylla* Trécul	16	1.43	1.82	1.94	15	15	6	6
23	*Aspidosperma discolor* A. DC.	14	1.25	4.99	1.67	14	14	0	0
24	*Matayba arborescens* (Aubl.) Radlk.	12	1.07	1.08	1.39	12	10	0	17
25	*Hirtella racemosa* Lam.	12	1.07	1.71	1.53	11	11	8	8
26	*Miconia holosericea* (L.) DC.	12	1.07	0.20	1.25	12	12	0	0
27	*Xylopia frutescens* Aubl.	11	0.98	0.39	1.39	8	7	27	36
28	*Tapirira guianensis* Aubl.	9	0.80	0.37	1.25	6	5	33	44
29	*Dacryodes* cf. *nitens* Cuatrec.	9	0.80	3.43	0.97	7	7	22	22
30	*Pera coccinea* (Benth.) Müll. Arg.	8	0.71	0.14	0.97	8	8	0	0
31	*Protium unifoliolatum* Engl.	7	0.62	0.09	0.97	6	5	14	29
32	*Lacistema pubescens* Mart.	7	0.62	0.07	0.83	7	6	0	14
33	*Vochysia ferruginea* Mart.	6	0.53	1.31	0.83	5	3	17	50
34	*Miconia dispar* Benth.	6	0.53	0.08	0.69	5	4	17	33
35	*Miconia* cf. *tetrasperma* Gleason	5	0.45	0.10	0.42	4	2	20	60
36	*Myrciaria dubia* (H.B.K.) Mc Vaugh	5	0.45	0.18	0.56	4	4	20	20
37	*Inga heterophylla* Willd.	5	0.45	0.09	0.69	4	4	20	20
38	*Maprounea guianensis* Aubl.	5	0.45	0.39	0.69	5	5	0	0
39	*Inga thibaudiana* DC.	4	0.36	0.06	0.56	3	3	25	25
40	*Virola sebifera* Aubl.	4	0.36	0.07	0.56	3	3	25	25
41	*Alibertia edulis* (L.C. Rich.) A. Rich.	4	0.36	0.07	0.56	4	4	0	0
43	*Cupania* cf. *scrobiculata* L.C. Rich.	4	0.36	0.06	0.56	4	4	0	0
44	*Hirtella bullata* Benth.	4	0.36	0.43	0.56	4	4	0	0
45	*Licania blackii* Prance	4	0.36	2.74	0.56	4	4	0	0
46	*Nectandra cuspidata* Ness & Mart.	4	0.36	0.13	0.42	4	4	0	0
47	*Micropholis venulosa* (Mart. and Eichler) Pierre	3	0.27	0.06	0.42	2	2	33	33
48	*Myrcia fallax* (Rich.) DC.	3	0.27	0.28	0.42	3	2	0	33
49	*Siparuna guianensis* Aubl.	3	0.27	0.05	0.28	3	2	0	33

Table 2 (*Continued*)

	Species	Initial population				Survivors		Tree mortality (%)	
		October 1999				December 1999 NI/ha	August 2000 NI/ha	December 1999	August 2000
		NI/ha	DeR	DoR	FR				
50	*Connarus perrottetti* (DC.) Planch.	3	0.27	0.12	0.42	3	3	0	0
51	*Inga laurina* Willd.	3	0.27	0.07	0.42	3	3	0	0
52	*Ormosia arborea* (Vell.) Harms.	3	0.27	0.13	0.42	3	3	0	0
53	*Vismia japurensis* Reichardt	3	0.27	0.06	0.42	3	3	0	0
54	*Sclerolobium paniculatum* Vogel	2	0.18	0.27	0.28	0	0	100	100
55	*Cecropia* cf. *distachya* Huber	2	0.18	0.13	0.28	2	0	0	100
56	*Thyrsodium spruceanum* Benth.	2	0.18	0.03	0.28	1	1	50	50
57	*Xylopia* cf. *ulei* Diels	2	0.18	0.13	0.28	1	1	50	50
58	*Dulacia inopiflora* (Miers) O. Kuntze	2	0.18	0.02	0.28	2	2	0	0
59	*Mabea fistulifera* Mart.	2	0.18	0.42	0.28	2	2	0	0
60	*Trichilia micrantha* Benth. & Hook	2	0.18	0.04	0.14	2	2	0	0
61	*Pouteria gardneri* (Mart. & Miq.) Baehni	2	0.18	0.05	0.28	2	2	0	0
62	*Campomanesia* sp.	1	0.09	0.01	0.14	0	0	100	100
63	*Palicourea guianensis* Aubl.	1	0.09	0.01	0.14	0	0	100	100
64	*Byrsonima crispa* A. Juss.	1	0.09	0.10	0.14	1	1	0	0
65	*Copaifera langsdorfii* Desf.	1	0.09	0.05	0.14	1	1	0	0
66	*Diplotropis triloba* Gleason	1	0.09	0.14	0.14	1	1	0	0
67	*Maytenus* sp. 1	1	0.09	0.09	0.14	1	1	0	0
68	*Maytenus* sp. 2	1	0.09	0.02	0.14	1	1	0	0
69	*Himatanthus sucuuba* (Spruce) Woodson	1	0.09	0.01	0.14	1	1	0	0
70	*Hymenaea courbaril* L.	1	0.09	0.01	0.14	1	1	0	0
71	*Licania kunthiana* L.	1	0.09	0.10	0.14	1	1	0	0
72	*Miconia* sp.	1	0.09	0.02	0.14	1	1	0	0
73	*Minquartia guianensis* Aubl.	1	0.09	0.03	0.14	1	1	0	0
74	*Simarouba amara* Aubl.	1	0.09	0.51	0.14	1	1	0	0
75	*Trattinickia* cf. *boliviana* (Swart.) Daly	1	0.09	0.06	0.14	1	1	0	0
76	Indeterminada	1	0.09	0.17	0.14	0	0	100	100

[a] NI: individuals number; DeR: relative density (%); DoR: relative dominance (%); FR: relative frequency (%).

In Pará, Cochrane and Schulze (1999), analyzing the damage caused by fire in an extensive area of Amazon forest, did not find a clear pattern of species selection, since the populations demonstrated similar mortality rates. In this case, the rare species may be more susceptible to local extinction than those which are more abundant. Even so, the authors admitted the possibility of the existence of species which are particularly resistant to fire in the cases of forests subjected to low intensity fires or in large-scale studies.

A good revision of the vegetative adaptations which may influence the survival of the Amazonian forest species subject to low intensity fires may be found in Kauffman and Uhl (1990). Thick bark, anomalous secondary growth and sprouting of subterranean germs or epicormics may be adaptations which may facilitate the persistence of individuals, whilst the viability of seeds in the soil, mechanisms of dispersal by the wind and an increase in the flowering after fire would facilitate the survival of populations.

Anomalous secondary growth is common in palms and lianas. The resistance of these life forms to fire have been frequently observed. Successive fires resulted in the dominance of vegetation by palm trees in Maranhão and in the south of Pará, where the babaçu (*Attalea speciosa* or *Orbignya phalerata*) stands out, or in Roraima where the inajá (*Attalea regia*) predominates (Fearnside, 1990). In the same manner, natural fires may possibly explain the unusual structure of the liana forest of the West Amazon region (Nelson, 1994).

Palm trees do not live in the stretch of burnt forest in Gaúcha do Norte studied. Lianas are not particularly common in the community structure, but liana seedlings were observed during the post-fire regeneration.

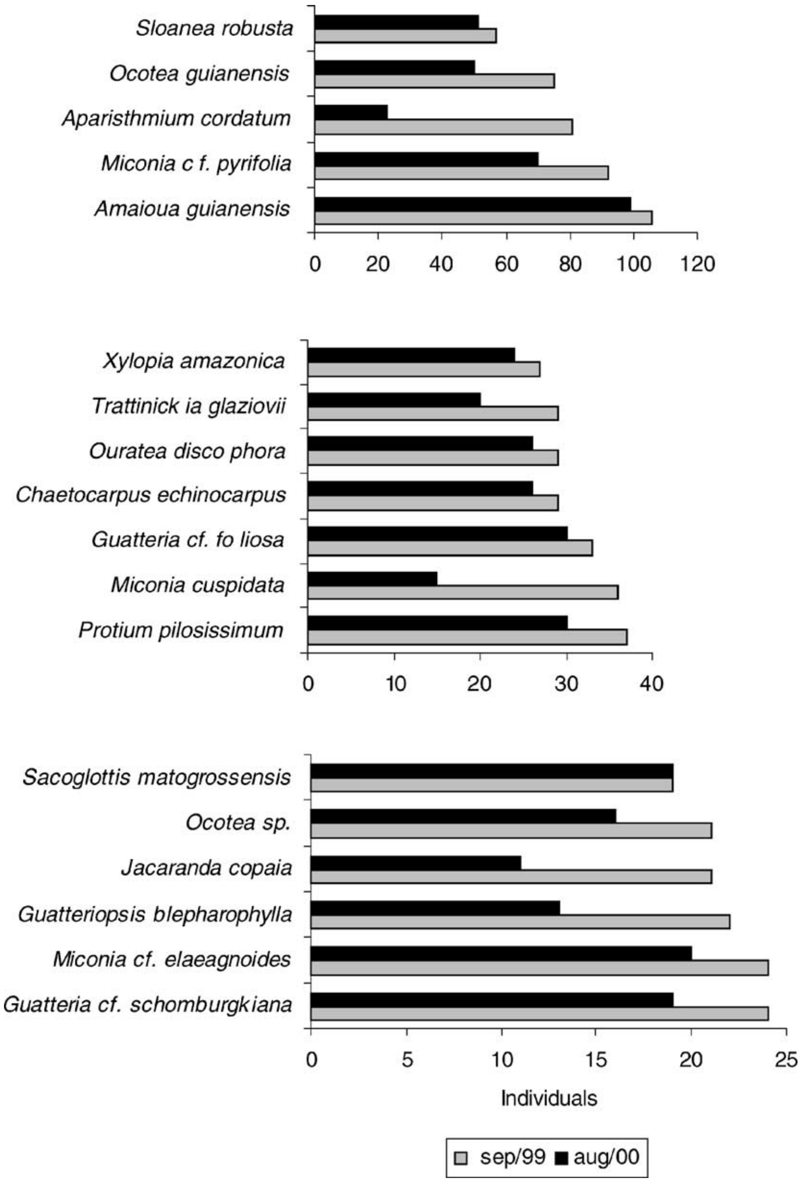

Fig. 5. Populations of some species in the period before (September 1999) and after (August 2000) a fire in an evergreen seasonal forest in Gaúcha do Norte, MT, Brazil.

Whether these seedlings will continue or even dominate the community in the future, associated or not with the repeated action of fires, remains to be seen and only long-term studies will be able to provide this information.

Of the vegetational adaptations to fire resistance which has most received attention from researchers is the type and thickness of tree bark, since bark has a thermal isolating function (Uhl et al., 1990; Uhl and Kauffman, 1990). Bark differs both in function of the size of the tree and in function of the species (Torres et al., 1994) and these differences may be fundamental in the determination of which vegetation may be capable of surviving fire (Uhl et al., 1990).

During a simulated fire, in which the external temperature of the bark of tropical forest trees was measured, the highest temperatures occurred in those trees with bark composed of fine exfoliations, which caught fire immediately when exposed to flames (Kauffman and Uhl, 1990). It was seen that temperature exchanges of above 60 °C, generally accepted to be fatal to plant tissues, occurred in trees with a bark thickness of less than 6.4 mm (Uhl et al., 1990). Unfortunately, the majority of the trees of tropical rain forests have fine bark, resulting in high mortality even when the forest is subject to a low intensity fire (Kauffman and Uhl, 1990).

Differences in bark thickness may explain some of the differences in the tree mortality of species which survived the fire in Gaúcha do Norte. *A. cordatum* has an extremely fine bark and is lightly exfoliated, both in young and adult individuals, which may have contributed to the severe reduction in its population, and similarly in *Miconia ligustroides*. *Jacaranda copaia* has a smooth to lightly fissured bark and does not survive temperatures of higher than 60 °C (Uhl and Kauffman, 1990). In contrast *A. guianensis* has a thicker bark with longitudinal fissures and was almost unaffected by the fire.

Those examples between species differences in fire tolerance can be considered as field observations, which must be better investigated scientifically. However, they cannot be discarded, since they would be important to the forest resilience.

4. Conclusions

After a fire, there is a significant increase in the nutrients in the soil, the pH is elevated and the aluminum toxicity decreases. However, the elevated rainfall results in losses by lixiviation and consequently the nutrient reserve in the soil is reduced to less than or the equivalent of that which existed before the fire.

Even in low intensity fires, the tree mortality was extremely high, principally affecting the youngest individuals of the population and those situated in border or clearing areas.

Fire plays a role in the selectivity of those species resistant or adapted to fires, since some have a greater tolerance to low intensity fire than others. In addition, the large majority of species suffer populational reductions in burnt areas and do not resist severe or frequent fires. Thus, fire severely affects the structure of these formations.

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