

Fire in the seasonal semideciduous forest: impact and regeneration at forest edges

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At the edge of forest fragments, tree recovery after fire is constrained by grasses and vines, which recover more quickly and are also more susceptible to fire.

Fire is one of the main factors causing biodiversity losses in tropical forests. Its main effects on ecological processes in these forests are losses in stocks of biomass, changes in hydrological cycle and nutrients (Salati and Vosep, 1984) and impoverishment of native plant and animal communities (Pinard, Putz and Licona, 1999), which may be followed by biological invasions (Mueller-Dombois, 2001).

Biodiversity losses are reported to be especially intense at forest edges. The lower humidity and greater number of dead trees (flammable material) make edges of fragmented forests more prone to frequent fires than the forest interior (Cochrane, 2003; Laurance *et al.*, 2001; Uhl and Kauffman, 1990). In addition, a higher density of lianas and exotic grasses from the surrounding pastures is common. Previous studies have found that lianas hamper the regeneration of fragments affected by fire (e.g. Castellani and Stubblebine, 1993; Rodrigues *et al.*, 2004) and that decreases in the density and richness of the seed bank after fire are greater at the edge of the forest (Melo, Durigan and Gorenstein, 2007). It could thus be expected that structural and floristic losses, as well as the resilience of plant communities, depend on the distance from the forest edge.

To test this hypothesis, the study reported in this article examined the effects of fire on plant communities at different distances from the edge of a fragment of seasonal semideciduous forest in Brazil. The article also characterizes the dynamics of the recovery of forest structure and species richness after the fire.

DETAILS OF THE STUDY

The studied area is in the northern part of the Ecological Station of Caetetus in the state of São Paulo, Brazil (22°23'17"S and 49°41'47"W). The climate is tropical with a dry season usually lasting from April to August. The forest is separated from neighbouring coffee plantations by a dirt road 5 m wide, where the invasive grass *Panicum maximum* proliferates.

An accidental fire occurred in October 2003, at the end of an exceptionally long dry season, burning an area about 60 to 80 m wide and 300 m long. This area was compared with a neighbouring unburned forest 40 m distant from the burned forest, having the same environmental conditions as the control.

Five permanent transects (10 m wide and 50 m long) were installed in each sector (burned and unburned), from the edge to the forest interior, each consisting of five plots of 10 x 10 m². A distance of at least 10 m was maintained between transects. For comparison, the plots were grouped into two strips according to their distance from the forest edge: 0 to 20 m (external) and 20 to 50 m (internal).

Six months after the fire, all individuals of arboreal species (at least 1.7 m tall) were identified, labelled, measured and categorized as:

- survivors: living trees with no signs of burned canopy;
- dead: plants with no leaves and no signs of regrowth;
- shoots: aerial structures burned, sprouts from the stem base or from roots up to a maximum distance of 50 cm from the stem;
- recruits: plants emerging from seed after the fire.

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Structural parameters and floristic richness of tree species in forest regeneration after fire compared with unburned forest at the Ecological Station of Caetetus, Brazil

Time after fire (months)	Basal area (m ² /ha)								Density (trees/ha)							
	Total		Surviving trees		Seed bank trees		Sprouting trees		Total		Surviving trees		Seed bank trees		Sprouting trees	
	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal
6	0.78	3.58	0	2.12	0.58	1.37	0.20	0.09	1 290	3 559	0	193	1 100	3 235	190	131
15	2.57	6.47	0	2.12	2.16	4.00	0.41	0.36	1 690	4 120	0	193	1 310	3 555	380	372
24	3.49	10.01	0	2.12	2.96	7.48	0.53	0.41	1 890	4 327	0	193	1 430	3 787	460	520
Not burned	20.68	20.26							1 870	3 607						

Time after fire (months)	Cover (%)						Number of tree species							
	Trees		Lianas		Grasses		Sprouting		From seed		Surviving		Total species richness	
	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal	External	Internal
6	20.0	50.6	79.9	69.3	11.8	0.6	8	10	6	10	0	16	14	26
15	47.7	85.6	81.2	70.1	13.4	1.8	13	22	11	13	0	11	19	32
24	47.3	87.5	85.2	76.9	14.1	0.1	15	23	13	23	0	11	24	37
Not burned	62.4	70.8	71.4	62.0	9.8	0							45	66

Vegetation cover was also assessed, in percentage of land occupied by the projection of the aerial structures (branches, leaves) in two parallel lines in each plot, 3 m from its lateral limits. Trees, lianas and grasses (*P. maximum* only) were measured separately.

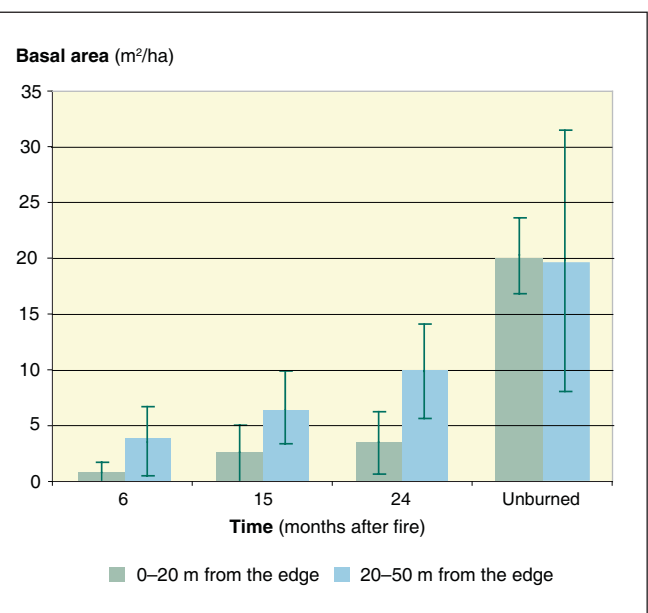
In the burned sector, all data were collected at 6, 15 and 24 months after the fire. In the unburned sector, data were collected 24 months after the fire.

INTENSITY OF DAMAGE

The fire caused damage of major consequence to the structure and floristic composition of the forest. Both internal and external strips of burned forest differed considerably from the unburned forest in tree density and biomass (represented by basal area) (Table). The shorter the distance from the edge, the higher the intensity of damage (Figure 1).

The estimated loss of biomass by fire ranged from 89 percent of the basal area in the internal strip to 100 percent in the external strip. The loss of biomass indicates the intensity of fire and there-

1
Arboreal basal area in different periods post-fire in comparison to unburned forest, Ecological Station of Caetetus, Brazil (vertical lines indicate standard deviation)



fore the degradation which the event may have caused the plant community (Kruger, 1984a; Whelan, 1995). In the external strip, where trees were fewer, the fire was probably more intense because of the greater availability of easily combustible grasses and lianas,

as well as the lower relative humidity normally found in edges of forest fragments (Forman, 1995).

RECOVERY OF STRUCTURE AFTER FIRE

The rate of forest recovery also varied with distance from the edge. Both the



Forest edge, two days after fire



Forest edge six months after fire; burned trees and high biomass of the grass Panicum maximum are visible



Forest edge 18 months after fire, with abundance of grasses and lianas climbing dead and living trees

vulnerability to fire and the recovery varied among species.

Overall, 24 months after the fire, the biomass measurement of the burned forest had not reached that of the unburned forest, and the recovery of biomass was slower in the external strip (Figure 1). At this time, trees from the seed bank or seed rain already accounted for the largest portion of the basal area (Table) as compared with surviving trees and sprouts of pre-existing individuals.

If the increase in basal area of the burned forest remained constant at the rate estimated for the first two years by regressions, the internal strip would require 5 years and the external strip 11 years to achieve their original biomass.

The tree canopy cover stabilized nearly 15 months after the fire in both strips but was higher in the internal strip.

The differences in tree biomass (density, cover and basal area) between the strips at 24 months after the fire can be explained by several factors:

- the density of trees was also lower closer to the edge before fire, decreasing the availability of sprouts for regeneration;
- the seed bank was considerably reduced in the external strip (Melo, Durigan and Gorenstein, 2007);
- the already scarce seedlings and sprouts of arboreal species in the external strip faced strong competition from vines and invasive grasses.

Grasses and lianas (from the seed bank or sprouting from suckers) quickly recovered in the burned area in the first six months after fire. Vines quickly covered the area during this time but did not increase considerably thereafter. Vines have a more diverse spectrum of adaptation to vegetative replication than trees (Gerwing, 2003) and have great capacity for regrowth, which ensures rapid occupation of disturbed sites, so they are obviously more abundant at the edges (Janzen, 1980; Putz, 1984).

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Increased frequency of lianas (woody and herbaceous) with increased intensity of fire has also been reported (Cochrane and Schulze, 1999).

The grass growth rates were very high. Coverage by *P. maximum* was always higher in the external than in the internal burned plots. It was also generally higher in the external burned strip than in unburned forest. Once established, grasses can reduce the light availability on the forest floor up to 99 percent (Hughes and Vitousek, 1993), impairing the germination and recruitment of tree species. In addition to hampering the development of tree species, grasses provide dry fuel in the winter, leaving the area prone to new fires.

IMPACT AND RECOVERY OF FLORISTIC RICHNESS

The response of plants to fire, even within the same population, depends on the intensity of fire in each location and the morphological characteristics and location of each individual (Whelan, 1995). Ivanauskas, Monteiro and Rodrigues (2003), studying the effects of fire in seasonal forests in Mato Grosso, Brazil, found mortality rates ranging from 0 to 100 percent among 76 species.

In the present study, the burned forest had, in general, much lower tree species richness than the unburned forest (Table). Of the 77 tree species sampled in the unburned forest, 43 (56 percent) were not sampled in the burned forest at 24 months after the fire.

The elimination of species in the burned forest can be temporary if the fire reaches only part of the forest, as they can be reintroduced by seed dispersal or wind. However, the results suggest that fire can lead to local extinction of some species if the whole fragment is burned.

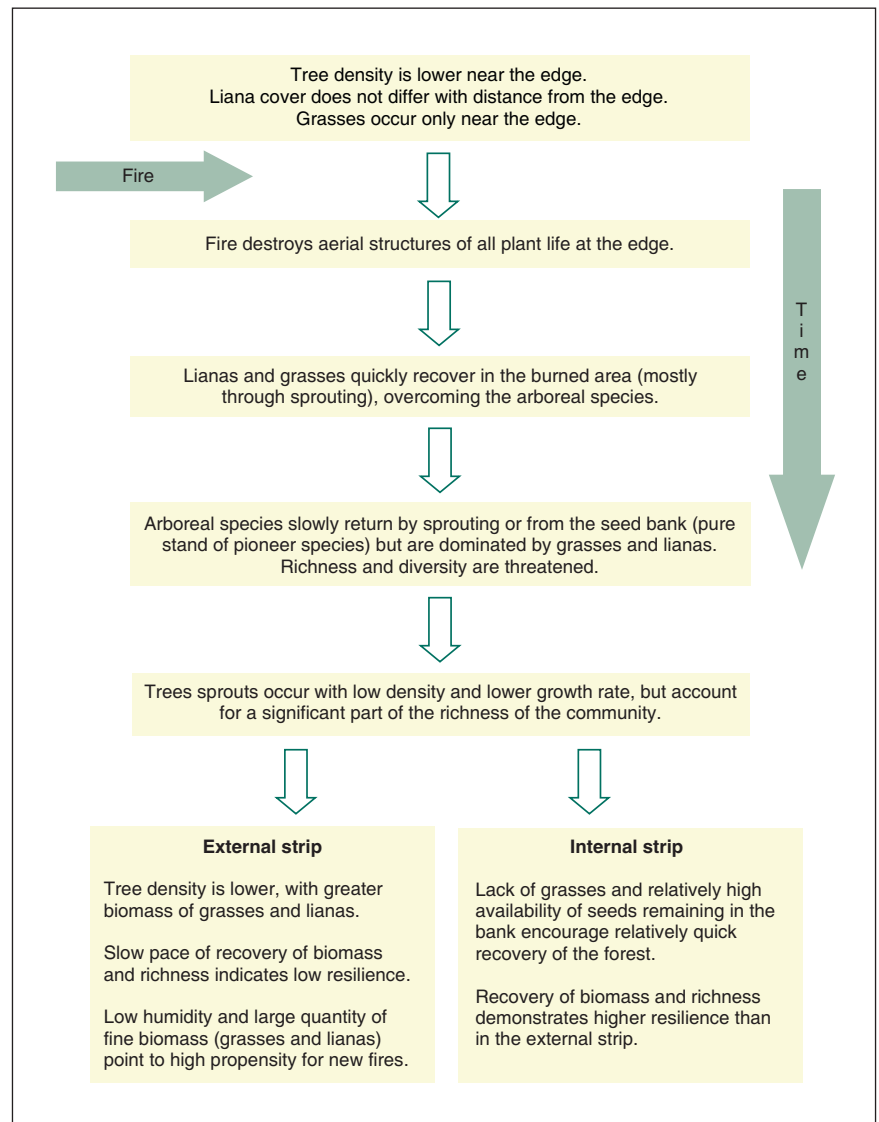
In general, both ranges from the edge showed an increase in the number of tree species throughout the period of monitoring (Table). Species returned over time, for a gradual recovery of the richness of the community. Even so,

24 months after the fire the burned forest still had fewer species than the unburned forest in both strips.

From the sixth to the twenty-fourth month after fire, a significant increase in the density of sprouts was observed in both strips. The importance of sprouting as a strategy for survival in post-fire regeneration has been reported for various tropical forest ecosystems (Uhl *et al.*, 1981; Kruger, 1984b; Rounw, 1993; Marod *et al.*, 2002; Kennard *et al.*, 2002).

Previous studies have shown that seasonal semideciduous forest has a considerable number of species capable of regrowth after fire (Castellani and Stubblebine, 1993; Hayashi *et al.*, 2001; Rodrigues *et al.*, 2004). However, the lack of long-term monitoring of burned communities makes it impossible to draw conclusions about fire as an element of evolutionary pressure in this type of forest.

2
Model proposed for two years of post-fire regeneration at the edge of seasonal semideciduous forest



CONCLUSIONS

Fire was a strong agent of degradation in the studied forest, almost completely destroying the arboreal biomass, as well as remarkably reducing species richness in the arboreal layer. Recovery of forest biomass was very slow (low resilience) in both strips.

Recovery of the forest structure was faster the larger the distance from the edge; this pattern appears to be related to the edge effects already existing before the fire.

The grasses, present almost exclusively near the forest edge, do not prevent the arrival of seeds but do inhibit germination, establishment and development of seedlings. Certainly their rapid proliferation in the post-fire community inhibits the development of arboreal species from the seed bank and affects the regenerating community. So, in the strip 0 to 20 m from the edge of the fragment, the density of trees is much lower than in the more internal strip, where grasses are virtually absent.

The results make it possible to infer a model for structural changes in fragments of semideciduous seasonal forest over a two-year period after fire (Figure 2). It is proposed that the rate of recovery of tree biomass is constrained mainly by the presence of grasses and vines which rapidly occupy the burned area and are highly flammable. The convergent conclusions from this and other studies (Cochrane and Schulze, 1999; Pinard, Putz and Licona, 1999; Cochrane, 2001, 2003; Mueller-Dombois, 2001; Slik *et al.*, 2008; Veldman *et al.*, 2009) suggest that the proposed model is applicable to other fragmented tropical forests wherever fire has been a persistent threat, exacerbated by edge effects in a vicious circle.

Management strategies for preventing fire damage in forest fragments should be directed towards controlling the proliferation of grasses and vines along the forest edges rather than just installing firebreaks. Shelterbelts of fire-resistant

and non-invasive species can be used to reduce light incidence at the forest edges to discourage growth of grasses, as an alternative to chemical control with herbicides. ♦



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