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Fire and restoration of the largest urban forest of the world in Rio de Janeiro City, Brazil

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Abstract. National Park of Tijuca in Rio de Janeiro (Brazil) is about 3,300 ha and considered the largest urban forest in the world. Its floristic composition is typical of Atlantic Rain Forest. The reserve is being altered because of fire occurrences and urban expansion. This study identified locations and causes of forest fires, and makes management recommendations to restore damaged areas. From 1991 to 2000, forest firefighters recorded an average of 75-fire occurrences/year. Identified causes included hot air balloons (24%), intentional (24%), rubbish burning (21%) and religious practices (17%). Primary fuels included invasive grasses and ferns. Although hot air balloons destroyed larger areas of forest in each occurrence, a greater number of fires started in the invasive vegetation along roads that bisect the forest. In response to recurrent forests, invasive vegetation has spread gradually into the forest increasing forest degradation. To decrease fire damage, sites with high fire frequencies and density of invasive vegetation were planted with less flammable species. Results indicate that fire frequency decreased and density of invasive vegetation declined. This approach appears to prevent fire incidence, reduce the need for fire fighting, and preserve existing biodiversity.

Keywords: wildfires, Atlantic Forest, Tropical Forest, conservation, Rio de Janeiro

Introduction

The Atlantic Rain Forest, in the southeast of Brazil, is one of the richest world ecosystems (Myers *et al.*, 2000) but has been reduced to 8% of its original area (SOS Mata Atlântica and INPE, 1993). Deforestation began with the influx of immigrants to the southeastern region of Brazil, in the 17th century, when large areas of forest were cleared for coffee plantations. Railway and road construction further accelerated fragmentation and deforestation. With the economic development of the last few decades, industries and urban areas have encroached further into the forest. In the state of Rio de Janeiro, the remaining forests are becoming

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increasingly fragmented and isolated. The Atlantic Forest, once covered 96% of the state's total area, is reduced to only 21% (IBDF, 1981; SEMA, 1991). Today, about 33 km^2 form the National Park of Tijuca, the largest urban reserve of the world (IBAMA, 2003).

In addition to deforestation, air pollution from adjacent factories and residential areas affect National Park of Tijuca (Oliveira and Lacerda, 1988; Oliveira and Lacerda, 1993). This problem is worse along the northern face (the continental face) when compared to the southern face (facing the Atlantic Ocean) (Oliveira *et al.*, 1995). The northern face receives winds from the continent that bring with them pollutants and is drier than the southern face. Annually, large areas of National Park of Tijuca are destroyed or impacted by fires or urban expansion. These effects and other impacts on the forest remnant remain practically unknown (Oliveira and Lacerda, 1988). Even with a history of human disturbances, National Park of Tijuca has high biodiversity and structural complexity, and offers opportunity for conservation.

Fire is a disturbance that fundamentally affects the establishment and maintenance of plant species and communities structure (Whelan, 1995; Goto *et al.*, 1996; Miranda *et al.*, 1996; Cochrane and Schulze, 1999; Cochrane, 2001). The occurrence of occasional fire events in a plant community allows the formation of different successional communities, whereas in communities where fire is recurrent, soil erosion and local extinction of native plants and animals become a problem (Primack, 1993; Whelan, 1995). Several studies have documented that fires are widespread in the tropics (Cochrane and Schulze, 1998, 1999; Peres, 1999; Gascon *et al.*, 2000; Cochrane, 2001). Because fire in the Atlantic Rain Forest is rare, fire events and their consequences at community level have not been evaluated. Such information is crucial to understand the current status of vegetation and to design an effective management strategy to restore damaged sites. This paper examines the characteristics of fire events occurring in the National Park of Tijuca, in terms of frequency, period, duration and main causes, and proposes a management strategy to restore most frequently burned sites.

Methods

Study site

The study was carried out in the National Park of Tijuca (22°57′9″ S and 43°18′3″ W) in the state of Rio de Janeiro. This park has a forested area of about 3300 ha and is surrounded by the city of Rio de Janeiro. The climate of this region has two distinct periods: the rainy season extends from October to March, when the mean temperature is about 25°C, and the dry season from April to September, when the temperature reaches 19°C (Oliveira *et al.*, 1985; Ito, 1997). The mean annual rainfall is approximately 2500 mm (Coelho Neto, 1985).

The region of Rio de Janeiro was discovered in 1502 by Portuguese navigators. Before that, its inhabitants were Indians that used the forest to hunt animals, and harvest fruits, seeds and woods (IBDF, 1981; Machado, 1992; Silva-Filho, 1992). Some plantations of manioc, a root eaten by natives, were already established. With the arrival of Portuguese settlers, large areas of forest were burned and converted to sugar-cane plantations

(Machado, 1992). In 1760, coffee plantations were established, which further deforested the region (Machado, 1992). By 1818, deforestation was forbidden to preserve the natural springs that supplied water to the city. According to Machado (1992), after the extreme dry season of 1844, several private areas within the forest were declared public and in 1861, a reforestation program was initiated. In 1961, after one hundred years, Floresta da Tijuca was created as a National Park, being one of the most interesting sites in Rio de Janeiro.

Fire characteristics

Data on fire events within the National Park were recorded by forest firefighters since 1991, the year the group was institutionalized. Information collected on a wildfire included the date, place, time, duration, extension (when available), type of vegetation (when available), and causes (when available) of each fire occurrence. Data gaps existed because firefighters did not record all the information for every fire event. The most critical places, defined as places having the highest number of fire events, were selected for restoration efforts.

Vegetation management

At frequently burned sites, which occurred primarily along forest borders, we observed *Panicum maximum*, Poaceae, an invasive grass. Sites preparation occurred in 1999 and included mowing grasses, and removing wastes and despoils from the border up to 10 m towards the forest interior. The soil was then revolved before the addition of Ca and Mg combined with organic matter (50 g/cavity). The size of cavities for native species was 30×30 cm and 20×20 cm for exotic species.

Herbaceous species introduced on prepared sites were *Impatiens walleriana* (Hook, F.) (Balsaminaceae), *Wedelia paludosa* (Compositae), *Sansevieira* sp. (Agavaceae) and *Zebrina pendula* (Commelinaceae). All are exotic, shade-intolerant species commonly used as ornamental plants in gardens. *Impatiens* is very common in forest borders of urban areas of the Atlantic Forest, having a high percentage of water content and forming a dense carpet that flourish over the whole year. An average of two hundred plants of native species, *Anadenanthera peregrina* (Leguminosae-Mimosoideae), *Piptadenia gonoacantha* (Leguminosae-Mimosoideae), *Tabebuia chrysotricha* (Bignoniaceae), *Tabehuia heptaphylla* (Bignoniaceae), *Eugenia uniflora* (Myrtaceae), *Myrciaria trunciflora* (Myrtaceae), *Inga* sp. (Leguminosae-Mimosoideae); two species of shrubs, *Hisbiscus* sp. (Malvaceae) and *Bouganvillea spectabilis* (Nyctaginaceae); and two exotic pioneer trees were also introduced: *Euphorbia tirucalli* (Euphorbiaceae) and *Mimosa caesalpiniaefolia* (Benth.) (Leguminosac-Mimosoideae). The success of plant species, especially herbs and shrubs, was evaluated six months after treatment in terms of % of dominance of the species in relation to the % of grasses found in the areas after the treatment, and number of fire occurrences observed in treated areas. Species nomenclature followed Joly (1987) and Lorenzi (1992, 1998).

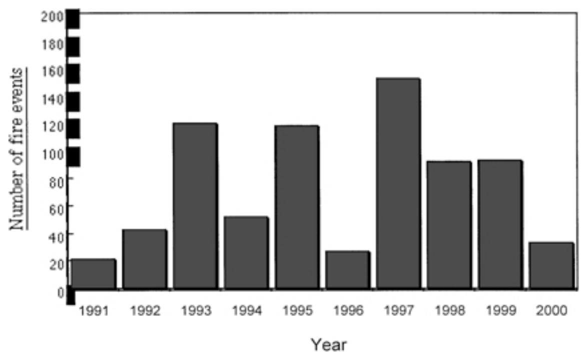

Figure 1. Number of fires occurring within National Park of Tijuca, Rio de Janeiro, Brazil, from 1991 to 2000.

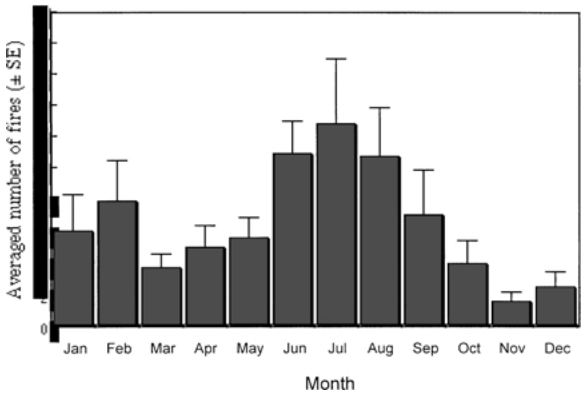

Figure 2. Mean number of fire (±se) by month occurring within National Park of Tijuca, Rio de Janeiro, Brazil.

Results

Fire characteristics

From 1991 to 2000, 781 (75 events/year) fire events were recorded within the National Park of Tijuca. These include large and small events. Three peaks in the frequency of fire/year were observed, in 1993, 1995 and 1997 (figure 1). Most fire events occurred during the dry winter season, from June to August, but a large number of events also were occurred in the afternoon during the summer rainy season, from January to March (figures 2 and 3). Most fire events took less than two hours to be controlled, including the time spent in transit (figure 4). Although data were not available for the whole period of study, a correlation between monthly averages of air temperature and number of rainy days ($r = 0.714$) did exist (figure 5). Lower correlations were observed between averages of air temperature ($r = 0.56$), number of rainy days ($r = 0.387$) and fire.

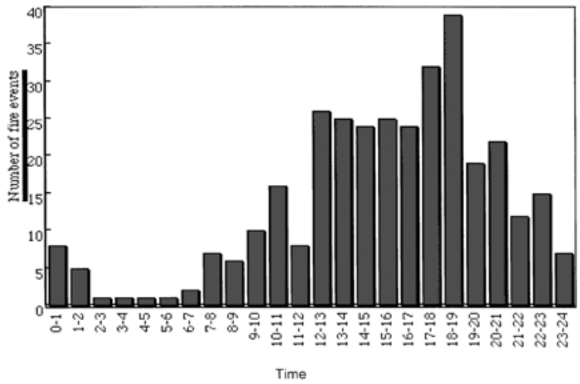

Figure 3. Pattern of fire occurrence during the day within National Park of Tijuca, Rio de Janeiro, Brazil.

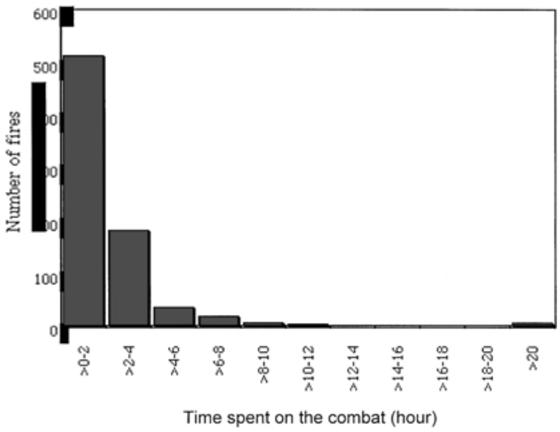

Figure 4. Time spent in the combating fires by the forest-firefighters from 1991 to 2000.

The causes of most fire events (88%) were not identified. Identified events included hot air balloons (24%), intentional (24%), religious practices (17%) and burning rubbish (21%). Hot air balloons consist of a light wire structure covered with a very thin cloth or paper opened in the bottom where a live flame device is located. In 1999, five events originated from lightning.

Vegetation management

Six months after treatment, several species of herbaceous and pioneer trees were already established on sites. The most successful was *Wedelia paludosa* (Table 2). This species spreads over the area, and required no further treatment. Although found in low density (about 4 plants/species/100 m^2) the pioneer trees colonizing treated areas were: *Trema micrantha* ((L.) Blum.) (Ulmaceae), *Cecropia pachystachya* (Trec.), *Cecropia glaziovi* (Snethlage)

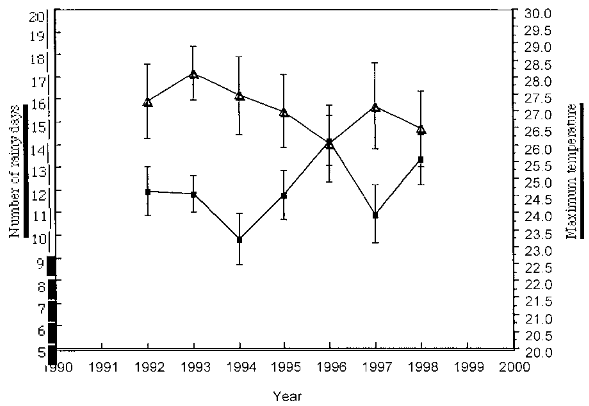

Figure 5. Mean (±se) of maximum temperature (°C, triangles) and number of rainy days (squares) obtained from the climate station nearest to the study site within the National Park of Tijuca. Data were obtained from Coordenadoria de Recuperação Ambiental/Secretaria Municipal de Meio Ambiente, Rio de Janeiro, Brazil.

(Cecropiaceae), *Mimosa bimucronata* ((DC.) O. Kuntze) (Leguminosae-Mimosoideae), *Psidium* sp. (Myrtaceae), *Machaerium hirtum* ((Vell.) Stellf.) (Leguminosae-Papilionoideae), *Leandra* sp. (Melastomataceae), *Miconia* sp. (Melastomataceae), *Tibouchina* sp. (Melastomataceae) and *Cedrela fissilis* (Vell.) (Meliaceae).

Grasses were still observed in some of the restored areas but not as frequent as before the treatment. Before the treatment sites were almost completely covered by grasses (more than 90% of the total area), whereas where *Wedelia paludosa* was successful, the presence of grasses was less than 10% of the vegetation. On the other hand, in control areas where this treatment was not carried out, grasses dominated (more than 90%) and in some of these places, the presence of other plant species was not observed. The total area treated was 9,600 m^2 at a cost of about US$ 20,000.00.

Table 1. Locations within the National Park of Tijuca, Rio de Janeiro with more than 1% of the total number of fires occurring from 1991 to 2000

Local	Number of fires	Percent of total (%)
Others	394	51
Estrada de Furnas	95	12
Rua Almiranic Alexandrino	85	11
Estrada do Sumaré	77	10
Avenida Edson Passos	41	5
Avenida D. Joaquim Mamede	27	3
Floresta da Tijuca	19	2
Estrada Capitão Campos	15	2
Estrada da Paz	12	2
Estrada das Paineiras	11	1

Table 2. Number of plants, spacing between plants, and evaluation comments by species for areas (9,600 m^2 total) restored in the National Park of Tijuca, Rio de Janeiro

Species	Number of plants	Density (plants/m^2) or spacing	Species response
Wedelia paludosa	56000	16 plants/m^2	Was very successful, its requirements included full sunlight, irrigation until its establishment (about 3 times) and an organic matter mantle (3–7 cm).
Zebrina pendula	10000	10 plants/m^2	Was successful in areas partially shaded, needs irrigation until its establishment (about 3 times) and organic matter mantle (3–7 cm). However, grasses persist at these sites.
Impatiens walleriana	400	30 × 30 cm	Was initially successful but after 3 months grasses re-established, was not successful in fully lighted areas and low humidity.
Sansevieira sp.	250	30 × 30 cm	Was successful during the maintenance period. It became dominant after 6 months but required periodical care. It is relatively expensive to maintain although useful to reduce percentage of grass cover.
Mimosa caesalpiniaefolia	2000	50 × 50 cm and 100 × 100 cm	This species grew approximately 2m during 1 year, shading the grasses and creating a green fence, which prevented entrance into the forest. It can also be flammable.
Euphorbia tirucalli	3500	50 × 50 cm and 100 × 100 cm	Was not successful because of frequent ant attacks. Its growth was lower than *Mimosa* and *Wedelia*.
Hisbiscus sp.	400	50 × 50 cm	Was successful because it grew fast and formed dense foliage having a beautiful aspect. However, it required longer care or otherwise grasses came back.
Bouganvillea spectabilis	400	50 × 50 cm	Similar to *Hibiscus* but grew slower

Estrada de Furnas and more specifically the sites were this project was carried out (according to personal information obtained from firefighters), had the highest number of fires during that period (Table 1). In terms of fire control, only one fire occurred on restored areas, and spread from the interior towards the forest edge (C. Junius, Director of Restoration Program, pers. commun.). In the other sections of the forest, fires occurrences was still high in 1999 and 2000 (Figure 1).

Discussion

In National Park of Tijuca of Rio de Janeiro, we observed a high frequency fire events (75/yr) with relatively short duration. Short duration may be related to the easy access and the proximity of firefighters. Most fire events took place at the forest edges along roads and were quickly extinguished. These fires were started by cigarettes or for intentional reasons, religious practices, and waste incineration. Fires along roadsides increase the potential of invasive species colonization (Milberg and Lamont, 1995). In the National Park of Tijuca recurrent fires (more than 9 fires/year), enabled invasive vegetation (e.g., *Pteridium aquilinum* and *Panicum maximum*) to spread further into the forest. Fires produced by hot air balloons occurred within the forest. The largest fire event took about four days to extinguish. Natural fires (e.g., lightning ignition) were rare in the Atlantic Rain Forest and only five occurred from 1991–2000.

The remarkable seasonality in terms of fire occurrences is related climate (Whelan, 1995). Increased fire susceptibility was related to two climatic conditions: (1) the hydric deficit during the winter dry season and (2) the short hydric deficit, which occurs during the afternoon of summer rain season. In addition, folk tradition of releasing hot air balloons during the dry season increased fire susceptibility. The risks associate to such traditions are unquestionable (New York Times 24/06/02), and include fatal accidents occurring during the release of the balloons, petroleum refineries placing fire brigade on high alert, and airline companies possibly cancelling flights to Rio de Janeiro and São Paulo. In the recent years, the government developed a reward system for citizens that provided information on the releases of hot air balloons. The high fire frequency during summer afternoons reflects a combination of moisture content, relative humidity and human activities. Moisture content in vegetation and relative humidity decrease through the day. By midday, both relative humidity and moisture content were at their lowest increasing the fire susceptibility.

In addition to fires destroying vegetation, urbanization also has decreased forest cover. Loss of forest cover has increased landslide frequencies and severity (C. Junius, pers. commun.). In 1998, residents were killed and homes were destroyed by landslides. An evaluation of reforestation projects is being conducted to reduce landslides. Current observations reveal that 80 sites have been restored, and landslide frequency has declined in these areas, even on steep slopes (C. Junius, pers. commun.). Furthermore, when restoration efforts used less-flammable plants, fire frequency also decreased. Our findings indicate that planting less-flammable vegetation in these fire prone areas, or around property and fire-sensitive natural areas, prevented ignition or slowed fire spread. The use of less-flammable species to reduce fire incidence is recommended by several other authors (Garcia *et al*., 1995; Hogenbirk and Sarrazindelay, 1995).

Although the flammability of plant species from the Atlantic Rain Forest has not been quantified, succulent shrubs and trees are assumed less flammable than grasses and ferns. The harmful attributes of *Pteridium aquilinum* and *Panicum maximum* are widely known (Watt, 1940; del Amo, 1991; Alonso-Amelot and Rodulfo-Baechler, 1996; Humphrey and Swaine, 1997; Calvert, 1998; Naturia, 2002) and include the high productivity and large accumulation of litter. In addition, these species affects the establishment of other plant species (Pakeman and Marrs, 1992; Calvert, 1998). Their high flammability also increases the intensity of fires in areas where fires were only patchy and low in intensity.

Although fire events were short, their frequency produced enormous changes in plant community (Zedler *et al*., 1983). Tropical trees are vulnerable to fire (Uhl and Kauffman, 1990). Frequent fires may create forested areas with less tree density and reduced regeneration (Cochrane and Schulze, 1999). Post-fire flush of seedlings and sprouting are adaptive traits in fire-dependent community (Whelan, 1995). In non-fire dependent communities (e.g., the Atlantic Rain Forest), however, the ability to resprout and recruitment from the soil seed bank may be seriously diminished with frequent fires. Lower regeneration may be especially problematic for the northern face of the National Park of Tijuca because of the negative effect of dry winds and low precipitation on plant survivorship and regeneration (D. Chevalier, Manager of the Management Project, pers. commun.).

In general, removal of grasses and ferns enable successional processes to occur (Fonseca *et al.*, 1998). In this urban forest, the restoration involved an fire prevention/control and was motivated by the desire to protect the beauty of these sites. National Park of Tijuca is considered the second most interesting place in the city (Silva Matos, 1999). With increased fires and species shifts to grasses, this beauty is being compromised, and more public funds must be spent fighting fires rather than managing the forest. Exotic species (e.g., herbs and shrubs) were not an ecological risks because they were light-demanding species and unable to grow in the forest interior. We created a less flammable vegetation of attractive paisagistic aspect with flowering herbs and native tree species. Based on this study, other areas of the National Park will be treated by replacing invasive vegetation with less flammable vegetation.

As pointed out by Bond and Midgley (1995), fire is a key, but neglected, evolutionary force. In tropical forests, fire is a growing problem because of human uses of fire (Uhl and Buschbacher, 1985). The synergism between forest fragmentation and altered fire regime impose risks to tropical forests and affects its management through shifts in species composition and increases in fuel loads (Cochrane and Schulze, 1999; Cochrane, 2001). Gill (2001) stated that the protection of human life and property from fire are universal requirements of fire management. Management needs to minimize fuel load and maximize fire suppression. By altering species composition, fire frequency can be reduced in large metropolitan forests. Likewise, with less funds diverted to fire fighting, more are available for forest management needs.

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