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USING THE VARIANCES OF MICROCLIMATE VARIABLES TO DETERMINE EDGE EFFECTS IN SMALL ATLANTIC RAIN FOREST FRAGMENTS, SOUTH-EASTERN BRAZIL

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One of the main questions raised by the effects of forest fragmentation is concerned with understanding of the environmental aspects that can induce changes in biodiversity. Despite its importance, there are relatively few studies focusing on the microenvironmental status of fragments, especially fragments of tropical forest of less than 100ha (Harrington *et al.* 1997, Turton & Freiburger 1997, Tabanez *et al.* 1997, Viana *et al.* 1997). Most of the literature on forest fragmentation is derived from larger fragments, specially those in Amazonia (Kapos *et al.* 1993, Kapos *et al.* 1997, Scariot 1999, 2000, Laurance *et al.* 2001) whose past and present status is completely different from the Atlantic rain forest.

The Atlantic rain forest, which originally occurred in a large expanse parallel to the Atlantic Ocean, is presently reduced to 8% of its original size (SOS Mata Atlântica 1998). According to Tanizaki & Pedrosa (1998) most forest fragments (87%) still found in Rio de Janeiro state are at most 2 km^2 which corresponds to 11.7% of the total forest remainder. The largest forest fragments are within national parks. The Atlantic rain forest has been considered one of the most important ecosystems in terms of the promotion of its conservation because of its high biodiversity and high proportion of endemic species (Myers *et al.* 2000). However, most biological aspects, and especially the microclimate status of these remnants, are practically unknown. No studies on microclimate alterations due to forest fragmentation in this ecosystem have been published.

Within this context, this study is a quantitative evaluation of the microclimate of three forest fragments of the Atlantic rain forest in Rio de Janeiro state, Brazil. We propose that variances of microclimate variables could be used to evaluate differences within forest fragments. We attempt to verify the presence of a “core area” as a guide to the management proposals for small forest fragments. As deforestation and fragmentation are still occurring, specially in Rio de Janeiro state (SOS Mata Atlântica 1998), knowledge of most ecological aspects of forest remnants is necessary and urgent for the promotion of their correct management.

The study was carried out in the National Biological Reserve of Poço das Antas (22°30’–22°33’S, 42°15’–42°19’W), Silva Jardim county, Rio de Janeiro state, south-eastern Brazil. The Reserve covers ca. 5000 ha of atlantic forest, with a perimeter of 44 km and maximum elevation of 205 m above sea level (Souza *et al.* 2000). Pastures, agriculture, and secondary forests surround the area. The regional climate is classified as Walter and Lieth’s Equatorial type (Walter 1971). Rainfall is well distributed throughout the year (average annual rainfall of 2092 mm, 1987–1997 period), with a less rainy period extending from May to August (Souza *et al.* 2000).

Within the reserve the study sites are located in three fragments belonging to the group of fragments known as “Ilhas dos Barbados”. In 1984, with the

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construction of a dam in that region, the soil was drained, thus increasing the impact on the vegetation through the death of trees and invasion of weeds. Nowadays these fragments are scattered in a matrix formed by grasses (where the dominant species is *Panicum maximum*) and bracken (*Pteridium aquilinum*). Fragment I is round in shape and is about 1.28 ha, fragment II is elongated and about 7.1 ha, and fragment III is also round and about 11 ha.

Within each fragment two perpendicular transects were established: North-South and East-West. The lengths were 120 m and 180 m respectively for fragment I, 180 m and 420 m for fragment II, and 330 m and 360 m for fragment III. Data on air and soil humidity, air and soil temperature, and air flow were collected from 10:00 h to 14:00 h along these transects (at 30 m intervals from edge to edge). Soil temperature (at 5 cm depth) was obtained using a soil thermometer (± 1 % accuracy), air temperature and humidity using a digital thermohygrometer (± 1 °C accuracy), and air flow using a digital anemometer at breast height. Measurements were obtained after values had become constant. Two measurements of air flow were taken at each point, one for each direction N-S and W-E, to obtain the components of the wind velocity. The wind speed is simply the modulus of the velocity (the square root of the sum of the squares of the components). One sample of soil (approximately 300 cm^3) was taken from each point to calculate the water content. These samples were weighed, dried at 80 °C for 48 hours and then weighed again. The distance to the edge was defined as the smallest distance along any axis. This definition is the same as the distance measured along the transects, except for the innermost points of measurement where the distance to the edge is less, especially in the case of fragment II.

Differences in air temperature (Ta), soil temperature (Ts), air humidity (Ha), and soil humidity (Hs) between the three fragments were evaluated using one-way ANOVA followed by Tukey's post-hoc to investigate differences between the means (Zar 1984). To evaluate the differences along the transects each of the four measurements (Ta, Ts, Ha, and Hs) went through a one-way ANOVA against the distance to the edge, followed by a Bartlett test for the variances, and finally a Tukey-like post-hoc to obtain the differences between the variances (Zar 1984). The data on wind speed had a distribution that was clearly not normal and so were excluded from these analyses due to the extreme sensitivity of the tests to normality.

Microclimate differs significantly between fragments (Table 1). In general the data show that the fragments are all different, though with one exception: soil humidity (only fragments II and III differ). Soil and air humidity were higher in the largest fragment and lower in the medium-sized fragment (ANOVA, df = 56 with F = 7.12, p = 0.0018 and F = 32.12, p = 0.0001 respectively). On the other hand, soil and air temperature were lower in the largest and higher in the medium-sized fragment (ANOVA, df = 56 with F = 27.62, p = 0.0001 and F = 24.48, p = 0.0001 respectively).

Grouping the data for each distance raises the issue of the independence of the data collected near the center of the fragment. We found that measurements in adjacent plots near the center of the fragment clearly do not correlate for soil temperature and humidity (r = 0.11, p = 0.81 and r = 0.37, p = 0.41 respectively). On the other hand, this is not true for air temperature and humidity (r = 0.82, p = 0.02 and r = 0.84, p = 0.02 respectively), so significance tests could be done only for Ts and Hs, while the other measurements were used only qualitatively.

TABLE 1. Summary of ANOVA results for the comparisons of microclimate variables of three Atlantic rain forest fragments. Data are least-square means (± SE) and n is the sample size. Least-square means cannot be distinguished statistically (Tukey test, p < 0.05) if they have the same superscript.

	Fragment I (*n* = 12)	Fragment II (*n* = 22)	Fragment III (*n* = 25)	SS	*F*	*p*
Soil humidity (%)	$19.10 \pm 1.33^{a,b}$	16.75 ± 0.98^{a}	21.83 ± 0.92^{b}	303.28	7.12	0.0018
Soil temperature (ºC)	22.64 ± 0.25^{a}	23.64 ± 0.19^{b}	21.81 ± 0.17^{c}	39.15	24.48	0.0001
Air humidity (%)	75.25 ± 1.77^{a}	68.77 ± 1.31^{b}	83.12 ± 1.23^{c}	2421.55	32.12	0.0001
Air temperature (ºC)	29.09 ± 0.48^{a}	30.68 ± 0.36^{b}	27.06 ± 0.33^{c}	154.21	27.62	0.0001

TABLE 2. Means (first line) and variances (second line) for air temperature (Ta), soil temperature (Ts), air humidity (Ha), soil humidity (Hs) and wind speed (W) measured at different distances from the edges of forest fragments. n is the sample size. Variances cannot be distinguished statistically (Tukey test, $p < 0.05$) if they have the same superscript (only for Ts and Hs).

	Ta (°C)	Ts (°C)	Ha (%)	Hs (%)	W (m/s)
0 m	29.26	23.67	76.17	20.19	0.79
n = 12	9.16	1.85^{a}	104.33	74.80^{a}	1.37
30 m	28.93	22.5	75.25	19.92	0.66
n = 12	7.89	0.82^{a}	114.39	$16.13^{a,b,c}$	1.38
60 m	29.07	22.47	74.00	18.89	0.22
n = 12	5.57	0.93^{a}	95.81	$28.89^{a,b}$	0.06
90 m	29.13	22.87	75.14	18.43	0.23
n = 14	2.79	1.28^{a}	50.75	$10.57^{b,c}$	0.09
120 m	27.37	21.52	81.75	20.01	0.15
n = 4	0.59	$0.26^{a,b}$	4.92	$8.22^{a,b,c}$	0.09
150 m	27.20	21.40	82.00	19.43	0.38
n = 5	0.52	0.02^{b}	5.50	2.34^{c}	0.27

Both means and variances indicate that there are microclimate differences between outer and inner parts of the fragments (Table 2). The Bartlett test for the variances shows clearly that they are different for Ts and Hs (Table 3). From Table 2 it can be noted that the variances change at a distance of about 120 m for Ts, while for Hs the change is at about 30–60 m. Air temperature and humidity also point to a change at about 90–120 m and wind speed indicates a change at about 30–60 m. The variances are plotted against the distance to the edge in Figure 1 in order to illustrate its qualitative behavior more easily.

Our results indicate that it is possible to define edge penetration distance through changes in the variance. We verify that for soil and air temperature and air humidity the edge penetration distance is noticeable up to 90–120 m, while for soil humidity and wind speed the edge penetration is only about 30–60 m. The evidence of an apparent uniformity at distances greater than 90–120 m from the edge indicates that rounded fragments greater than 10 ha would be able to keep a core area where soil and air temperature, soil and air humidity, and wind speed are relatively less variable than closer to the edges. Our results agreed with the findings of Silva Matos *et al.* (1998a, 1998b) for the vegetation structure in these fragments. In the smaller fragments the density of trees was lower, the trees were significantly shorter and had greater DBH (diameter at breast height), while the density of pioneer species (*Trema micrantha* and *Cecropia glaziovi*) and their penetration distance towards the interior were significantly higher. Changes in vegetation structure and floristics up to 100 m from the edge were also noticed in a 9.5 ha fragment of semi-deciduous forest (Tabanez *et al.* 1997, Viana *et al.* 1997). This is clear evidence that our findings are accurate and compatible with the studies involving biological aspects of fragmentation for fragments in the same size scale.

Saunders *et al.* (1991) pointed out a number of microclimate variables linked to edge effects, such as

TABLE 3. Summary of Bartlett test (B_c) for homogeneity of variances of microclimate variables measured at different distances from the edges of forest fragments.

	soil temperature	soil humidity
B_c	15.73	21.37
F	2.98	4.06
df	5	5
p	0.011	0.001

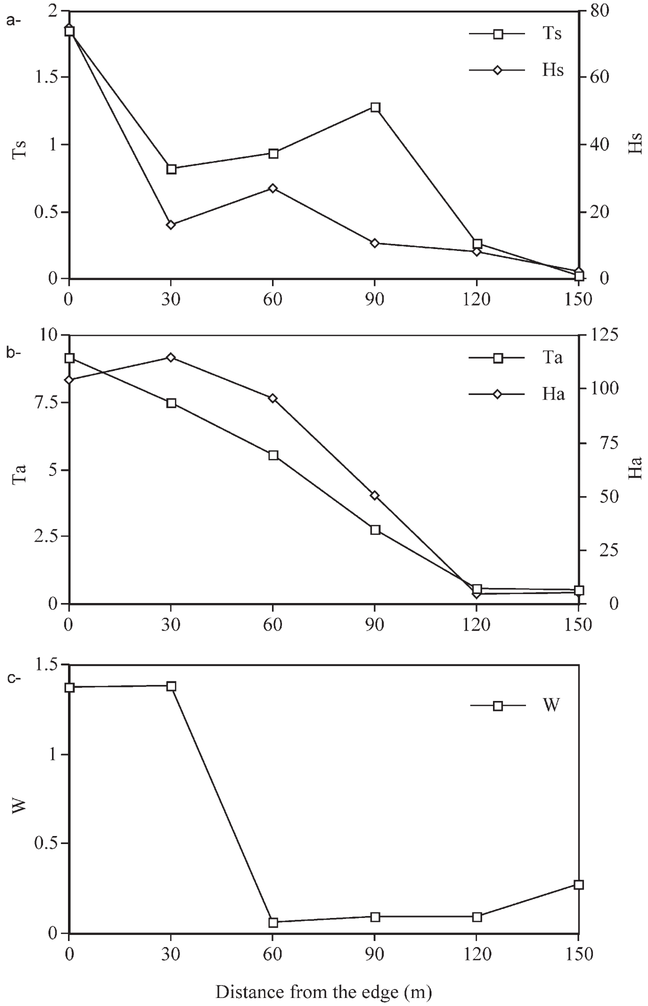

FIG. 1. Variances plotted against the distance to the edge: a - soil temperature and humidity, b - air temperature and humidity and c - wind speed.

flux of radiation, wind and water, temperature, and nutrient cycling. The variables sampled in this study gave good insights into differences in edge penetration. Although Didham & Lawton (1999) suggested that wind penetration should be detectable to greater distances than air temperatures we observed that wind speed became uniform at relatively short distances from the edge due to the "shielding" provided by vegetation. Data on air temperature and humidity, which could be affected by wind speed, indicate a much deeper effect of the edge. Probably even when wind speed is uniform it sustains its capability to carry humidity and heat, producing effects on air humidity and temperature at distances much further from the edge. Soil temperature and humidity also produce two different distances for edge penetrations, indicating a complex relationship between the many microclimate variables. Newmark (2001) observed that the shapes of the microclimate gradients also have a temporal variation. The results appear to show that near the edge temporal variance is greater than near the centers indicating that the use of variances to determine edge effects is not restricted to spatial variability. From these results it appears that it is important to use as many as possible microclimate variables in order to obtain a more accurate and complete determination of core area.

The use of variances of the microclimate variables rather than averages has allowed us to obtain a sharper definition of the distance of penetration of edge effects. While the averages do indicate that there is some differences between the outer and inner parts of the fragments, this was not corroborated by statistical analysis. On the other hand, when using variances it was easy to see that there are two regions: the "core", where variances are low and the edges, where the variances are much higher. These results could also be confirmed by statistical analysis in the case of Ts and Hs.

The results obtained in this study demonstrated that even for fragments of reduced size there is a core area where microclimate is less severe and much more uniform than at the edges. The existence of this uniform area is perhaps one of the factors that sustain the vegetation structure and species composition in these fragments (Pessoa 1998, Silva Matos 1998a, 1998b, Souza *et al.* 2000), their faunal composition (Oliveira 2001), and probably their ecological functions in a state more similar to larger forest remnants. Furthermore, these results are also very important for the conservation of the study site (Reserva Biológica de Poço das Antas) because the reason for its creation, the golden lion tamarins (*Leontopithecus rosalia*) (IBAMA 1989), were observed within small areas belonging to the same group of fragments (Fernandez 1998). Several other mammal species observed within the fragments include *Tamandua tetradactyla*, *Dasypus novemcinctus*, *Nasua nasua*, *Cerdocyun thous*, *Hydrochaerus hydrochaeris*, *Dasyprocta leporina*, *Cebus apella* and *Alouatta fusca* (Fernandez 1998). Therefore small fragments are potential habitats for important species like these and probably for many other forest interior species.

Associated with deforestation, fire is a growing problem in the tropics because of its widespread use in pastures or threatened forests (Uhl & Buschbacher 1985, Cochrane & Schulze 1999, Cochrane 2001). The synergism between forest fragmentation and fire increases the risks to Amazonian forest remnants, even the large ones (Cochrane & Schulze 1999, Gascon *et al.* 2000, Laurance 2000, Cochrane 2001, Cochrane & Laurance 2002). Although natural fire in the Atlantic rain forest is rare, human-induced fire increases edge penetration, intensifying the severity of subsequent fires through the expansion of flammable vegetation (e.g., grasses and ferns) (Silva Matos *et al.* 2002), and prevents successional processes occuring (Fonseca *et al.* 1998). Small forest fragments could be, in this case, totally replaced by fire-tolerant species. Considering that most of the Atlantic rain forest fragments are reduced in area like the fragments studied here (Turner & Corlett 1996, Ranta *et al.* 1998, Silva & Tabarelli 2000) their conservation status should be reviewed. Our findings support the idea of Tabanez *et al.* (1997) that small fragments also deserve to be preserved and more research on them is necessary.

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